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TRUEMAN'S

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ELEMENTARY BIOLOGY

Vol. I for Class XI

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Syllabus—XI & NEET

I. DIVERSITY OF LIVING ORGANISM

What is living ? Biodiversity; Need for classification; Three domain of life; Taxonomy and Systematics; Concept of species and taxonomical hierarchy; Binomial nomenclature; Tools for study of Taxonomy-Museums, Zoos, Herbaria, Botanical gardens.

Five kingdom classification; Salient features and classification of Monera; Protista and Fungi into major groups; Lichens; Viruses and Viroids.

Salient features and classification of plants into major groups-Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms (three to five salient and distinguishing features and at least two examples of each category); Angiosperms–classification up to class, characteristic features and examples.

Salient features and classification of animals—non-chordate up to phyla level and chordate up to classes level (three to five salient features and atleast two examples).

II. STRUCTURAL ORGANISATION IN ANIMALS AND PLANTS

Morphology and modifications; Tissues; Anatomy and functions of different parts of flowering plants; Root, stem, leaf, inflorescence-cymose and racemose, flower, fruit and seed (To be dealt along with the relevant practical of the Practical Syllabus).

Animal tissues; Morphology, anatomy and functions of different systems (digestive, circulatory, respiratory, nervous and reproductive) of an insect (cockroach), (a brief account only).

III. CELL: STRUCTURE AND FUNCTION

Cell theory and cell as the basic unit of life; Structure of prokaryotic and eukaryotic cell; Plant cell and animal cell; Cell envelope, cell membrane, cell wall; Cell organelles– structure and function; Endomembrane system–endoplasmic reticulum, Golgi bodies, lysosomes, vacuoles; mitochondria, ribosomes, plastids, microbodies; Cytokeleton, cilia, flagella, centrioles (ultra structure and function); Nucleus–nuclear membrane, chromatin, nuclecus.

Chemical constituents of living cells; Biomolecules-structure and function of proteins, carbohydrates, lipid, nucleic acids, Enzymes–types, properties, enzymes action.

Cell division : Cell cycle, mitosis, meiosis and their significance.

IV. PLANT PHYSIOLOGY

Transport in plants; Movement of water, gases and nutrients; Cell to cell transport-Diffusion, facilitated diffusion, active transport; Plant-water relations-Imbibition, water potential, osmosis, plasmolysis; Long distance transport of water-Absorption, apoplast, symplast, transpiration pull, root pressure and guttation; Transpiration–Opening and closing of stomata; Uptake and translocation of mineral nutrients–Transport of food, phloem transport, Mass flow hypothesis; Diffusion of gases (brief mention).

Mineral nutrition: Essential minerals, macro and micronutrients and their role; Deficiency symptoms; Mineral toxicity; elementary idea of Hydroponics as a method to study mineral nutrition; Nitrogen metabolism-Nitrogen cycle, biological nitrogen fixation.

Photosynthesis : Photosynthesis as a means of Autotrophic nutrition; Where does photosynthesis take place? How many pigments are involved in Photosynthesis (Elementary idea); Photochemical and biosynthetic phases of phtosynthesis; Cyclic and

Non cyclic photophosphorylation; Chemiosmotic hypothesis; Photorespiration; C3 and C4 pathways; factors affecting photosynthesis.

Respiration : Exchange of gases; Cellular respiration - glycolysis, fermentation (anaerobic), TCA cycle and electron transport system (aerobic); Energy relations-Number of ATP molecules generated; Amphibolic pathways; Respiratory quotient.

Plant growth and development : Seed germination; Phases of plant growth and plant growth rate; Conditions of growth; Differentiation, dedifferentiation and redifferentiation; sequence of developmental process in a plant cell; Growth regulators-auxin, gibberellin, cytokinin, ethylene, ABA; Seed dormancy; Vernalisation : Photoperiodism.

V. HUMAN PHYSIOLOGY

Digestion and absorption, Alimentary canal and digestive glands, role and digestive enzymes and gastrointestinal hormones; Peristalsis, digestion, absorption and assimilation of proteins, carbohydrates and fats; Calorific value of proteins, carbohydrates and fat (for box item not to be evaluated); Egestion; Nutritional and digestive disorders-PEM, indigestion, constipation, vomiting, jaundice, diarrhoea.

Breathing and Respiration; Respiratory organs in animals (recall only); Respiratory system in humans; Mechanism of breathing and its regulation in humans-Exchange of gases, transport of gases and regulation of respiration, Respiratory volume. Disorders related to respiration-Asthma, Emphysema, Occupational respiratory disorders.

Body fluids and circulation; Composition of blood, blood groups, coagulation of blood; Composition of lymph and its function; Human circulatory system-Structure of human heart and blood vessels; Cardiac cycle, cardiac output, ECG; Double circulation; Regulation of cardiac activity; Disorders of circulatory system-Hypertension, Coronary artery disease, Angina pectoris, Heart failure.

Excretory products and their elimination: Modes of excretion-Ammonotelism, ureotelism, uricotelism; Human excretory system-structure and function; Urine formation, Osmoregulation; Regulation of kidney function-Renin-angiotensin, A trial Natriuretic Factor, ADH and Diabetes insipidus; Role of other organs in excretion; disorders-Uraemia, Renal failure, Renal calculi, Nephritis; Dialysis and artificial kidney.

Locomotion and Movement; Types of movement - ciliary, flagellar, muscular; Skeletal muscle-contractile proteins and muscle contraction; Skeletal system and its functions (To be dealt with the relevant practical of Practical syllabus); Joints; Disorders of muscular and skeletal system-Myasthenia gravis, Tetany, Muscular dystrophy, Arthritis, Osteoporosis, Gout.

Neural control and coordination: Neuron nerves; Nervous system in humans-central nervous system and peripheral nervous system and visceral nervous system; Generation and conduction of nerve impulse; Reflex action; Sensory perception; Sense organs; Elementary structure and function of eye and ear.

Chemical coordination and regulation : Endocrine glands and hormones; Human endocrine system-Hypothalamus, Pituitary, Pineal, Thyroid, Parathyroid, Adrenal, Pancreas, Gonads; Mechanism of hormone action (Elementary Idea); Role of hormones as messengers and regulators, Hypo-and hyperactivity and related disorders (Common disorders e.g., Dwarfism, Acromegaly, Cretinism, goiter, exophthalmic goiter, diabetes, Addision's disease).

Imp. : Diseases related to all the human physiology systems to be taught in brief.

CONTENTS

*Earthworm and Frog discussed in this chapter are meant for competitive exams.

Source of Biological Terms

Most of the words in biology have been derived from Greek (Gk.) and Latin (L.) languages, because the pioneers of biology were natives of Greek and Latin speaking areas. Take advantage of the Greek and Latin roots of biological terms to break them down into their parts. For example, erythrocytes (*erythro* = red, *cyte* - cell) are red cells.

Prefixes

They are placed before the word to add to or change its meaning.

Prefix	*Meaning*	*Examples*
a–	without (negative prefix)	acellular, asexual, amorphous, abiotic
an–	without	anaerobic, anamniote, anaesthetic
amphi–	two/ on both sides	amphibian
anti–	against	antiseptic
ante–	in front of, before	antenatal
ad–	near, towards	adrenal
archae–	ancient	archaeologist, archaeology
arbor–	tree	arboreal
auto–	self	automatic
bi–	two, twice	bisexual
cyclo–	circle, ring	cyclostome
cephalo–	head	cephalothorax (head + thorax)
circum–	around	circumference
de–	down, reverse, opposite of	degenerate, deamination, removal, detoxification, dehydration, decarboxylation
deca–	ten	decade
di–	two, twice	disaccharides, dimorphism
dia–	through, across	diaphragm
epi–	on	epidermis
ecto–	outer	ectoderm
endo–	inner	endoderm
eu–	well	eukaryote
fore–	before, infront of	foregut, fore brain
haemo–	of the blood,	haemorrhage, haemoglobin
hemi–	half	hemisphere, hemiparasite
hetero–	different	heteropolysaccharides, heterocercal tail
homo–	same	homopolysaccharides, homocercal tail
hyper–	beyond, above	hypertension, hyperparasite
hydro–	of water	hydration
hypo–	under	hypotension
holo–	complete	holoparasite, holozoic, holophytic
inter–	between	intercellular
intra–	inside	intracellular, intravenous
later–	side	lateral
juxta–	nearer to	juxta glomerular apparatus
leu–	white	leucocyte
litho–	stone	lithosphere
macro–	relatively large	macromolecules
mega–	large	meganucleus, megakaryocyte
melan–	black	melanin
meso–	middle	mesoderm
meta–	change, after	metamorphosis, metathorax

micro–	relatively small	micromolecules
mono–	one	monosaccharides, monogamous
neo–	new	neo-natal, Neo-Lamarckism, Neo-Darwinism
neuro–	of the nervous system	neurology
oligo–	small, few	oligosaccharides
omni–	all, universe	omnivorous
para–	parallel	parasympathetic, parapodia
penta–	five	pentose
pro–	before, first	prostomium, prophase
peri–	around	periphery, peristomium
poly–	many	polymorphism, polysaccharides, polygamous
pre–	before	premedical, precaval
proto–	first, origin, basic	protoplasm, protozoa
pseudo–	false	pseudopodia
post–	after	post caval
re–	again	regeneration
retro–	backward	retrogressive
semi–	half, partially	semicircular
super–	above	superior
sub–	under	submandibular, subspecies
sym, syn–	with, together	symphysis, synthesis
tele–	linking across distances	telophase
uni–	one, the same	unicellular, uninucleate, unisexual
ultra–	beyond	ultra-violet

Suffixes

They are added at the end of a word to make another word.

Suffix	*Meaning*	*Examples*
–asis	condition or state	homaeostasis
–blast	young cell	osteoblasts, chondroblasts, fibroblasts
–cyte	cell	osteocytes, chondrocytes
–cide	killer	insecticide, weedicide, pesticide
–cule	small	animalcule
–ectomy	cutting out	prostectomy, vasectomy, tubectomy
–itis	inflammation	hepatitis
–lemma	membrane	plasmalemma, sarcolemma
–logy	branch of learning	biology, zoology
–lysis	dissolution, destruction, loosing	haemolysis
–osis	a process	metamorphosis
–ous	having the quality of	poisonous
–phyte	plant	bryophytes, pteridophytes, hydrophytes, xerophytes
–phil	lover	hydrophilic
–phobia	fear	hydrophobia
–tomy	cutting	autotomy

General Practice in Naming Biological Terms

(i) **On the basis of origin,** *e.g.,* protozoans—(*proto*—first, *zoans*—animals) animals which originated first.

(ii) **On the basis of location,** *e.g.,* extrinsic proteins—proteins found outside the cell membrane, intrinsic proteins— proteins found inside the lipid (fat) layers of cell membrane, interstitial cells—cells found in between other cells.

(iii) **On the basis of shape or structure,** *e.g.,* cubical cells —cube like cells.

(iv) **On the basis of colour,** *e.g.*, erythrocytes— (*erythro*—red, *cytes*—cells) —red blood cells, leucocytes (*leuco*—white, *cytes*—cells)— white blood cells.

(v) **On the basis of composition**, *e.g.*, carbohydrates (carbo— carbon, hydro— water) —with carbon, hydrogen and water, lipoprotein —with lipid (fat) and protein.

(vi) **On the basis of function,** *e.g.*, phagocytes—cells which kill and engulf microorganisms.

(vii) **After the name of the scientist,** *e.g.*, Golgi complex, Golgi— name of scientist.

Sometimes the terms do not indicate their actual meanings, for example— nucleic acids; when they were first discovered they were observed in the nucleus, therefore, they were named nucleic acids. Later on nucleic acids were also discovered in the cytoplasm but their names were not changed. Endoplasmic reticulum was so named because it was found in the endoplasm (inner portion of the cytoplasm), later on it was also observed in the ectoplasm (outer portion of the cytoplasm) but its name was not changed.

Words often Misunderstood

Atlas. In Greece Atlas was considered a demigod who was supposed to bear the world on his shoulders. This is first vertebra on which the skull lies. Atlas is also a book of maps.

Adam's Apple. It is another name of larynx (voice box).

Acellular. It means without cell.

Aristotle's Lantern. It is a masticatory apparatus of sea urchin. It is named after its discoverer and because of its resemblance to ancient Greek ship lantern.

Apposite. It means suitable, right, for the purpose or occasion.

Arabic Indian Numerals. 1, 2, 3, 4, 5, etc. **Roman Numerals.** I, II, III, IV, V, etc.

Amoeba is free living protozoan, however *Entamoeba histolytica* is an endoparasitic protozoan.

Blindworm, mud puppy, congo eel and mud eel are amphibians.

Cray fish, shrimp, wood louse and water flea are members of class crustacea, phylum Arthropoda.

Crocodile tears. Crocodile has no tear glands. So there are no tears in crocodiles.

Comb jellies are not jellies but are Ctenophores.

da. It means 'of' in Italian language. Example Leonardo da Vinci (1452–1519), Italian painter and inventor who is regarded as 'Father of Paleontology'.

de. It means 'of' in French language. Example : Hugo de Vries (1848–1935), Dutch botantist who is one of the independent rediscoverers of Mendelism. He proposed **mutation theory** and is regarded as "Father of Mutation Theory".

Darwin's finches are birds of Galapagos islands which were named as Darwin's finches by Dr. David Lack (1947).

Duck billed platypus is an egg laying mammal.

Elephant's tusk shell, sea hare, sea lemon, sea butterfly, razor fish, scallop, devil fish, cuttle fish and ship worm are molluscs.

Gila Monster is a poisonous lizard.

Gene pool. All the genes of all the individuals in a population make the genepool.

Germ. Microorganism, to form.

Glass snake is a limbless lizard.

Egestion means removal of undigested food (faecal matter). **Excretion** is removal of metabolic waste.

Fowl refers to both cock or hen.

Hermit is one who retires from society to live a solitary life, or a saint who lives in cave.

Hag fish is not a true fish. It is a cyclostome.

Horn toad is a desert lizard.

Ileum is part of small intestine. **Ilium** is part of pelvic girdle (hip girdle).

Island Rail is a flightless bird.

King of herrings (rabbit fish) is a cartilaginous fish.

King crab is not a crab. It is a member of clas Merostomata. However, its phylum is the same, *i.e.*, Arthropoda, as that of crab.

Male Koel sounds like *Kuoo-Kuoo,* however, female Koel has a short and sharp call *kik-kik-kik*.

Midwife is a trained woman who assists a mother in child birth.

Milk plant is the complete equipment including the building required for processing the milk.

Mosaic is a picture of pattern produced by putting together small pieces of coloured glass, marble or stone.

Memoir is a written account usually the book form of interesting and memorable experiences of one's life.

Mental concerning brain, **Mantle** means covering.

Mussel is a bivalved mollusc. It is called SIPPI in Hindi.

Mermaid purse refers to the egg capsule of sharks and skates.

Niche is hollow space in a wall for statue or candle or lamp. It is called 'AALA' in Hindi.

Owl has always been considered wise in the west, from the days of the Greek civilisation. In India it stands for foolishness.

Portuguese man of war, sea pen, sea fan, jelly fish and 'sea wasp' are cnidarians (coelenterates).

The phrase "the survival of the fittest" was first used by Herbert Spencer (1820–1903).

Rennin is a digestive enzyme secreted by the stomach to digest milk protein. **Renin** is secreted by the kidneys which is an enzyme but acts as hormone and changes the plasma protein, the angiotensinogen (prodoced by the liver) into angiotensin II.

Silver fish, house cricket, praying mantis, white ants (not ants but are termites), silk moth, *vespa* (genus of wasp) are insects.

Star fish, brittle star, sea urchin, sea cucumber, feather star, sea lily are echinoderms.

Sting ray and electric ray are cartilaginous fish.

Sea potato is an urochordate.

Sea horse, Bombay duck, climbing perch, eel, and seabass are bony fish.

Sea cow is herbivorous marine mammal.

Sewerage plant is the complete equipment for processing the sewer water which includes waste water and refuse.

Shell fishes are molluscs, each has a shell in two halves. They are used for food. Examples. Mussels, oysters, etc.

Stool is faeces or seat without arms or back.

Senile refers to old age.

Tongue worm is not worm but it is a hermichordate.

Typical. This word refers to a representative or symbolic or distinctive type.

Trichocyst is a structure present in *Paramecium* and some other protists, meant for anchoring or defence. **Nematocyst** (stinging 'organ') is a part of nematoblast (stinging cell) found in cnidarians (coelenterates), used for defence and offence.

Venus Flower Basket is a sponge whose skeleton is given a marriage gift in Japan.

Walking worm is a member of class Onychophora, phylum Arthropoda.

Wisdom teeth are third molars in human beings which are vestigial and are not concerned with wisdom.

Whale, dolphin, bat and flying fox are mammals.

Some terms and their related meaning

Term		*Related meaning*
arbor	–	tree
auditory	–	hearing
arthro	–	joint
acoustic	–	sound
andro	–	male
aster	–	star
aqueous	–	watery
aquatic	–	water
annual	–	lasting for a single year or season
amyl	–	starch
anthrop	–	man
adipose	–	fat
anus	–	posterior most opening of the alimentary canal
aerobic	–	air
albumen	–	the white of an egg
albumin	–	a protein
biennial	–	lasting for two years
branchial	–	gill
brachial	–	fore limb
buccal	–	mouth/oral
caudal	–	tail
cardiac	–	heart
cervical	–	neck
motor	–	muscle
mandible	–	lower jaw
maxilla	–	upper jaw
medial	–	nearer middle line of body
me[illegible]	–	black
nuptial	–	marriage
nasal	–	nose
nostrils	–	[illegible] of the nose
nocturnal	–	night
oesophagus	–	food pipe
olfactory	–	smell
oculo	–	eye
ophthalmic	–	eye
ornitho	–	bird
oligo	–	few
octo	–	eight
otic	–	ear

Term		*Related meaning*
coronary	–	heart
chromo	–	colour
chloro	–	green
cereb	–	brain
cyanin	–	blue
chemo	–	chemical
cyno	–	blue
coel	–	hollow
cutaneous	–	skin
cloaca	–	chamber to receive faecal matter and urine. It may receive reproductive fluid containing gametes.
counter	–	opposite
diurnal	–	day
distal	–	away from the attachment
dorsal	–	towards upper surface or back
epidemic	–	a disease effecting many persons at the same place and time.
marrow	–	substance
perennial	–	living for many years
phyco	–	algae
palaeo	–	ancient
phago	–	eat
phobia	–	fear
pulmonary	–	lung
penta	–	five
pectoral	–	shoulder
podia	–	feet
pleural	–	lateral side
pleura	–	lateral side (sing. pleuron)
pharynx	–	throat
pelvic	–	hips
palate	–	roof of the buccal cavity

Levels of Complexity

Sub atomic particles	Electrons, protons, etc.
Atom	Smallest unit of a chemical element, *e.g.*, carbon, hydrogen, oxygen, nitrogen.
Molecule	Group of two or more atoms, *e.g.*, sugar, protein, water, etc.
Organelle	Group of molecules which performs particular function, *e.g.*, Ribosome, mitochondria, etc.
Cell	Group of organelle and molecules, smallest unit capable of an independent life, *e.g.*, nerve cell.
Tissue	Group of cells which have similar structure, function, and origin, *e.g.*, muscular tissue.
Organ	Group of tissues performing a particular function, *e.g.*, stomach.
Organ-system	Group of organs performing a particular function, *e.g.*, digestive system.
Organism	Is a single celled or many celled living body which is able to collect, store and utilize energy, matter and information necessary for its own development and reproduction.
Population	A group of organisms of a species living in the same environment.
Community	All the population living in a given environment.
Ecosystem	The community and its non-living environment.
Biosphere	All the ecosystems of the earth (earth's surface that is occupied by living organisms).
Earth	Biosphere and components of earth.
Solar system	Sun and planets.
Universe	The entire cosmos.

Pronunciation/Silent Letters/Sound

If a word is pronounced properly, it is not difficult to spell. Some examples of unusual pronunciations are mentioned below :

Initial letters	*Pronounced*		*Examples*
pn	n	—	pneumonia, pneumatic bones
ps	s	—	psychology, psammosere, pseudopodia
pt	t	—	pteridophytes, pterygoid bone
x	z	—	xiphoid bone, xerophyte, xerosere
oe	e	—	oesophagus, oedema, oestrogen,
wr	r	—	wrist, wriggler, wrap, write, wright, wrong, wrought
ct	t	—	ctenidium
lk	k	—	yolk, folk
kn	n	—	knee, knob, knot, knife, know, knock

Some words give similar sound but have different spellings, *e.g.*, (i) their, there (ii) to, two, too (iii) rain, rein, reign (iv) cite, site, sight.

Nouns end in "**us**" *e.g.*, mucus. Adjectives end in "**ous**", *e.g.*, mucous glands, tremendous.

British and American Spellings

There are differences between some British and American spellings. Some words end in *ou* in British English and *or* in American English (*e.g.*, colour/color). Some word end in *tre* in British English and *ter* in American English (*e.g.*, centre/center). Some verbs can end with *ize* or *ise* in British English but they end with *ize* in American English (*e.g.*, realize/realise). Some examples are given below :

British English	American English	British Engli	American English
ageing	aging	haemoglobin	hemoglobin
anaemia	anemia	haemorrhage	hemorrhage
anaesthetic	anesthetic	honour	honor
analyse	analyze	litre	liter
centre	center	leucocyte	leukocyte
coelom	celom	metre	meter
coeliac	celiac	oesophagus	esophagus
caecum	cecum	oedema	edema
colour	color	oestrogen	estrogen
defaecation	defecation	oestrous	estrus
faeces	feces	paediatric	pediatric
fibre	fiber	programme	program
foetus	fetus	taenia	tenia
goitre	goiter	theature	theater
gynaecology	gynecology	traveller	traveler
haematuria	hematuria	tumour	tumor

In India, British spellings are commonly used.

ABBREVIATIONS AND SYMBOLS

ABA	Abscisic Acid
ABP	Androgen Binding Protein
ADP	Adenosine diphosphate
AMP	Adenosine monosphosphate
ARI	Acute respiratory infection
ACD	Acid citrate dextrose
ACTH	Adrenocorticotropic hormone
ATP	Adenosine Triphosphate
ATPase	Adenosine Triphosphatase
BAP	Benzyl amino purine
BHC	Benzene hexachloride
BMR	Basal metabolic rate
CAD	Coronary Artery Disease
CCK	Cholecystokinin
CCMB	Centre for Cellular and Molecular Biology Hyderabad
CPCB	Central Pollution Control Board
CPD	Citrate phosphate dextrose
CAP	Catabolite activator protein
COD	Chemical oxygen demand
CSIR	Council of Scientific and Industrial Research, New Delhi
CHD	Coronary heart disease
CRD	Chronic respiratory diseases
CP	Creatine Phosphate
CA	Cardiovascular arrest
CVA	Cardiovascular accident
CAT	Computerized Axial Tomography
CT Scan	Computed Tomography Scanning
CCC	Convention on climate change
DMPA	Depot-medroxyprogesterone acetate
DPGA	1, 3-bisphosphoglycerate
EFA	Essential Fatty Acids
EDTA	Ethylene diamino tetra-acetic acid
ET	Embyo transfer
ECG	Electrocardiogram
EEG	Electroencephalogram
ESR	Erythrocyte sedimentation rate
ECT	Electro convulsive therapy
EMP Pathway	Embden Myerhof Parnas Path way
FAS	Foetal Alcohol Syndrome
FSH	Follicle Stimulating hormone
GMP	Guanosine monophosphate
GTP	Guanosine triphosphate
GAP	Glyceraldehyde 3-phosphate
GEAC	Genetic Engineering Approved Committee
GPP	Gross Productivity
GFC	Grazing Food Chain
GEM	Genetically Engineered
GFR	Glomerular filteration rate
GSI	Gametophytic Self Incompatibility
HND	Haemolytic disease of the New born
HSV	Herpes Simplex virus
HPV	Human Palilloma Virus
HGP	Human Genome Project

HPL	Human Placental Lactogen
IBWL	Indian Board of Wildlife
ICBN	International Code for Botanical Nomenculture
ICZN	International Code for Zoological Nomenculture
IC	Inspiratory Capacity
IDDM	Insulin-dependent diabetes mellitus
LASER	Light amplification by stimulated emission of radiation
LAB	Lactobacillus bacteria/Lactic Acid Bacteria
LH	Luteinizing Hormone
LHC	Light Harvesting Complex
MET	Magnetoencephalography
MI	Myocaridal Infarction
NAD	Nicotinamide adenine dinucleotide
NADP	Nicotinamide adenine dinucleotide phosphate
NFWP	National Family Welfare Programme
NCP	National Commission on Population
NEERI	National Environmental Engineering Research Institute, Nagpur
NMR	Nuclear Magnetic Resonance
NAA	Naphthalene Acetic Acid
PEN	Primary Endosperm Nucleus
PEE	Piezo Electric Effect
*p*H	Hydrogen ion concentration, a measure of acidity or alkalinity
PPLO	Pleuro pneumonia-like organism
PVS	Potato Virus S
ppm	parts per million
ppb	pars per billion
PET	Positron emission tomography
PID	Pelvic inflamatory disease
PAN	Peroxyacetyl Nitrate
PAR	Photosynthetically Active Radiation
PCT	Proximal Convoluted Tubule
Ri Plasmid	It induces quick rooting in host organism after injection
RUBISCO	Ribulose bisphosphate carboxylase oxygenase
Rh	Rhesus
RNase	Ribonuclease
SA node	Sinoatrial node
STH	Somatotropic hormone
SQUID	Superconducting quantum interference device
SUZI	Subzonal insemination
Sv40	Simian Virus 40
SAFA-test	Solid Antigen Fluorescent. Antibody Test — It is a modification of ELISA - test
SSI	Sporophytic Self Incompatibility
TCA	Tricarboxylic acid cycle
TV	Tidal volume
TLC	Total leucocyte count Total lung capacity
TPP	Thiamine pyrophosphate
TPA	Tissue Plasminogen Activator
Ti Plasmid	Tumour inducing Plasmid
UTRs	Untranslated Regions
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organisation
UNDP	United Nations Development Programme
UQ	Ubiquinone
VAM	Vesicular Arbuscular Mycorrhiza
VC	Vital Capacity
WFN	World Wildlife Fund for Nature
WCU	World Conservation Union
WHO	World Health Organisation
WCP	World climate programme
YAC	Yeast artificial chromosome
♀	Female
♂	Male
☿	Bisexual

UNITS OF MEASUREMENTS

1 million	=	1,000,000, 10^6
1 billion	=	1,000,000,000, 10^9
1 trillion	=	10^{12}
1 quadrillon	=	10^{15}
1 kilometre (km)	=	1000 metres
1 mile	=	1.6093 km
1 hectare=		10000 m^2 = 2.471 acre
1 acre	=	4940 square yards = 4046.86 m^2
1 metre (m)	=	100 cm, 39.37 inches
1 yard	=	91.44 cm = 0.9144 m
1 foot	=	30.48 cm = 0.3048 m
1 inch	=	2.54 cm
1 centimetre (cm)	=	10^{-2} m = 10 mm
1 millimetre (mm)	=	10^{-3} m = 0.1 cm = 1000 μm
1 micron (μ)	=	10^{-6} or one-millionth
1 micrometre (μm)	=	10^{-6} m, 10^{-4} cm, 10^{-3} mm = 1000 nm
1 nanometre (nm)	=	10^{-9} m, 10^{-7} cm, 10^{-6} mm, 10^{-3} μm = 10E
1 angstrom (E)	=	10^{-10} m, 10^{-8} cm, 10^{-7} mm, 10^{-4} μm, 10^{-1} nm
1 picometre (pm)	=	10^{-12} m, 10^{-3} nm
1 femtometre (fm)	=	10^{-15} m, 10^{-6} nm
1 attometre (am)	=	10^{-18} m, 10^{-9} nm
1 tonne (t), metric tonne	=	1000 kg
1 ton (long ton)	=	1016.05 kg (= 2240 lbs)
1 quintal	=	100 kg
1 kilogram (kg)	=	1000 g = 2.2 lb
1 pound (lb)	=	0.4536 kg = 453.6 gm
1 ounce (oz)	=	0.0283 kg = 28.3 gm
1 gram (gm, g)	=	10^{-3} kg
1 milligram (mg)	=	10^{-6} kg, 10^{-3} g
1 microgram (μg)	=	10^{-9} kg, 10^{-6} g
1 gallon (gal)	=	4.546 litres
1 U.S. gallon	=	3.785 litres
1 litre (l)	=	1000 ml = 1 cubic decimetre
1 millilitre (ml)	=	10^{-3} l = 1 cubic centimetre
1 Dalton	=	1.66 x 10^{-24} g (weight of single hydrogen atom

1 THE LIVING WORLD

What is Living ?

Life is a unique, complex organisation of molecules that expresses itself through chemical reactions which lead to growth, development, responsiveness, adaptation and reproduction. The objects exhibiting growth, development, responsiveness and other characteristics of life are designated as **living beings**. They have their own specific form and structure. Based on these characteristics, the living objects can be recognised as trees, shrubs, cattle, birds, fungi, bacteria, etc. However, a specific shape, size and structure is also present in many non-living objects such as brick or rock. No single trait of life can distinguish a living being from a non-living object. Therefore, a number of traits are examined simultaneously to differentiate living beings.

Characteristics of Living Beings

1. **Cellular Structure**. It is **defining property of living beings**. Each living being is a complex entity which is formed of one or more cells. The cells are made of **protoplasm**, popularly called **living matter**. Composition of living matter is known. However, we have not yet been able to create protoplasm because of lack of organisation of biomolecules. Protoplasm and cellular structure are absent in viruses.

2. **Metabolism.** All organisms operate a network of thousands of chemical reactions. The sum total of all chemical reactions occurring in an organism due to specific interactions amongst different types of molecules within the interior of cells is called **metabolism** (Gk. *metabole*— change). Metabolism is **defining property of living beings**. All activities of an organism including growth, movements, development, responsiveness, reproduction, etc. are due to metabolism. No non-living object shows metabolism. However, metabolic reactions can be carried out outside the body of an organism in cell free systems. Such reactions are neither living nor nonliving. The isolated *in vitro* metabolic reactions can, however, be called **biological reactions** or living reactions as they involve biochemicals.

Types. Metabolism is of two kinds, catabolism and anabolism. **Anabolism** includes all the **"building up" reactions.** It is also called **constructive metabolism** since it involves the synthesis of complex substances from simpler ones, *e.g.*, synthesis of organic compounds from CO_2 and H_2O during photosynthesis, formation of starch from glucose, production of proteins from amino acids, formation of lipids from fatty acids and alcohols. Energy is stored (as potential energy) in the process.

$$6CO_2 + 12H_2O \xrightarrow[\text{enzymes}]{\text{chlorophyll, light energy,}} C_6H_{12}O_6 + 6H_2O + 6O_2\uparrow$$

$$n\,C_6H_{12}O_6 \xrightarrow{\text{enzymes, energy}} \underset{\textit{Starch}}{(C_6H_{10}O_5)n} + nH_2O$$

Catabolism (= katabolism) constitutes "**breakdown reactions**". It is also known as **destructive metabolism** because it involves breaking of complex substances into simpler

ones. Potential energy present in the complex substances is converted into kinetic energy. Respiration is an example of catabolism. It releases energy for performing different body activities.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzymes}} 6CO_2 + 6H_2O + \text{energy}$$

Differences between Anabolism and Catabolism

Anabolism	*Catabolism*
1. It is the sum total of building up or constructive processes.	1. Catabolism is the sum total of breakdown or destructive processes.
2. Anabolism produces complex materials from simpler ones.	2. It forms simple substances from complex ones.
3. It stores energy.	3. It releases energy.
4. Kinetic energy is changed into potential energy.	4. Potential energy is changed into kinetic energy.
5. Anabolism is required for growth, maintenance and storage.	5. Catabolism is required for performing various activities of living beings.
6. Fewer types of precursors form diverse products (reactions diverge).	6. Many types of larger substances breakdown to form fewer types of simple molecules (reactions converge).

3. **Growth.** Growth is irreversible increase in mass of an individual. A multicellular organism increases its mass by cell division. In plants, growth continues throughout life as they have meristematic areas where cell divisions occur regularly. In animals, growth occurs to a certain age after which cells divide only to replace worn out and lost cells. Unicellular organisms also grow by cell division. However, cell division is also a means of reproduction in them. In higher animals and plants, growth and reproduction are mutually exclusive.

Living organisms show internal growth due to addition of materials and formation of cells inside the body. Such a method is called **intussusception** (L. *intus* — within, *suscipere*— to receive). A dead organism does not grow. However, some nonliving articles can increase in size, *e.g.*, mountains, boulders, crystals, stones. It is due to addition of similar materials to their outer surface. The process is called **accretion** (L. *accrescere* — to increase). In living beings growth producing substances are of two types, protoplasmic and apoplasmic. **Protoplasmic substances** are components of living matter like cytoplasm and nucleus. **Apoplasmic substances** (Gk. *apo*– away, *plastos* – formed) are nonliving materials formed by the cells which become component of tissues, *e.g.*, cell wall, fibres of connective tissue, matrix of bone and cartilage.

Chemically growth is a result of difference between anabolism and catabolism. Growth occurs when anabolism exceeds catabolism. There will be no growth if anabolism and catabolism are equal. **Degrowth** or negative growth can occur when catabolism exceeds anabolism.

4. **Reproduction.** It is the formation of new individuals of the similar kind — *life arises from pre-existing life*. Reproduction is not essential for survival of the individuals. It is required for perpetuation of a population. Ability for reproduction develops when a young individual becomes mature. Reproduction is of two types, asexual and sexual. Asexual reproduction is **uniparental** while sexual reproduction is generally **biparental. Asexual reproduction** is the formation of new individuals from specialised or unspecialised parts of

a single parent without the formation and fusion of gametes. It occurs by **spores**, binary fission, multiple fission, fragmentation and regeneration. **Sexual reproduction** involves the formation and fusion of two types of sex cells or gametes. The fusion product or zygote gives rise to an offspring.

In unicellular organisms, growth and reproduction are synonyms. Many organisms do not reproduce, *e.g.*, mules, sterile worker bees, infertile human couples. Therefore, reproduction is not an all inclusive characteristic of living organism. However, no **nonliving object** has the power to reproduce or replicate.

5. **Consciousness.** It is awareness of the surroundings and response to external stimuli. The external stimuli can be physical, chemical or biological. The stimuli are perceived by sense organs in higher animals, *e.g.*, eyes, ears, nose. Plants do not possess such sophisticated sense organs. However, they do respond to external factors such as light, water, temperature, pollutants, other organisms, etc. **Photoperiods** (duration of daily exposure to light) influence reproduction in those animals and plants which breed during particular season (seasonal breeders).

All organisms, from primitive prokaryotes to most advanced and complex eukaryotes, are able to sense and respond to environmental factors. Organisms also handle chemicals entering their bodies. Human beings have an additional faculty of **self consciousness** (awareness of self). **Consciousness is said to be the defining property of living organisms.**

If a patient is lying in coma and is supported by machines for various functions, self consciousness and consciousness to external environment are supposed to be absent. Some of these patients never come back to normal life. They can neither be called living nor nonliving or dead.

6. **Organisation**. A living being has an **organisation**, that is, the living being consists of several components and subcomponents which cooperate with one another for the well being of the whole organism. A living being has multiple level organisation. Each level of organisation has its own properties which are not found in its constituents. A cellular organelle develops a property not found in its interacting molecular components. A living cell has its own characteristics not found in its organelles. A tissue is able to have a trait not found in its constituent cells.

7. **Energy**. Living beings constantly require energy not only to perform various activities of the body but also to overcome entropy or tendency to randomness. The source of energy is food. It is required by every cell of the body.

8. **Homeostasis (Homoeostasis)**. A favourable internal environment suitable for the functioning of body organs is present in every living being. It is quite different from the external environment. Changes in external environment do not have much impact on the internal environment as the living beings have a self regulated system to adjust and maintain the internal environment. The phenomenon is called **homeostasis** (Gk. *homois* — alike, *stasis* — standing). Homeostasis is also present in each cell of a multicellular organism.

9. **Variations**. Living beings possess variations and have the ability to evolve with time.

10. **Adaptations** (L. *ad*– toward, *apt* - adjust). *Useful inheritable variations or changes in form, function and behaviour which help an organism to adjust well and successfully in its environment are called adaptations.* An organism is considered best adapted to an environment when it possesses inherited traits that enhance its survival and ability to reproduce in that environment. Adaptations allow the organisms to overcome seasonal and other changes in the environment. They are of two types, **short term adaptations** (*e.g.*, hiber-

nation in most amphibians and reptiles and some mammals) and **long term adaptations** (*e.g.*, the claws of different birds are well adapted to suit their perching habits).

11. **Healing and Repair.** Living beings can repair and heal the broken and injured parts.

12. **Disposal of Wastes**. Wastes generated by living beings are regularly disposed off.

13. **Movements**. Living beings show movements of their parts. Some are able to move from place to place. The phenomenon is called **locomotion**.

14. **Life Span.** Every living organism has a definite life span of birth, growth, maturity, senescence and death.

15. **Death.** The stoppage of various life activities by an individual organism accompanied by increase in entropy is called death. Death occurs due to ageing, disease, accident and predation. Ageing normally occurs in all organisms after a period of reproductive maturity. It is, however, absent in some cases where the organism multiplies by binary fission, *e.g.*, *Amoeba*, bacteria. A fully grown *Amoeba*, or a bacterium divides into two daughters. In the process it loses its independent existence. Here, natural death is absent and the organism is immortal.

Living organisms are, therefore, self replicating, evolving and self regulatory interactive systems capable of responding to external stimuli, sharing a common genetic material to varying degree both horizontally and vertically.

DIVERSITY IN THE LIVING WORLD (BIODIVERSITY)

Diversity in the living world or **biodiversity** is the occurrence of a wide variety of life forms differing in morphology, size, colour, anatomy, habitats and habits. Each different kind of plant, animal or microorganism represents a species. Currently there are some 1.7–1.8 million living organisms known to science. Out of these 1.25 million are animals. The plants number about 0.5 million. The single group of insects, however, outnumber all the plants and other animals. This group contains about 1.025 million species. Every year about 15000 new organisms used to be discovered. The number has increased since the launching of projects like Global Biodiversity Information Facility and Species 2000. It is estimated that any number between 5 to 30 million species of living organisms are present on earth. Most of the unknown occur in the dense tropical rain forests and underwater reefs. Tropical rain forests are less than 8% of the total land. Their area is shrinking due to human exploitation. It is feared that if this exploitation is not stopped forthwith, many of the species will become extinct forever before coming to light. Because of this, the Silent Valley rain forest of Kerala has been saved from submergence under proposed dam across river Kuntizha.

The past organisms have also left their impressions or remains in the rocks. They are called **fossils**. The term **microfossils** is used for impressions and remains of microorganisms as well as microscopic remains of larger organisms. It is believed that the extinct species may out-number the living ones by 50–100 times. With such a large number of living and extinct organisms, it is essential to have a proper universal system of nomenclature, identification and classification that can bring out their true relationships. They are all domains of systematics.

Terminology

1. **Systematics** (Gk. *systema*– order, sequence). Systematics is a term often used interchangeably with taxonomy. According to Simpson (1961), systematics is the science that deals with diversity of organisms and all their comparative and evolutionary relationships based on study of comparative anatomy, development, comparative biochemistry, compara-

tive physiology and comparative ecology by grouping of organisms at every level of classification right from species to the kingdom.

2. **Taxonomy** (Gk. *taxis*– arrangement, *nomos*– law, de Candolle, 1813). It is the branch of study that deals with principles and procedures of identification, nomenclature and classification of organisms.

3. **Classification.** Classification is the arrangement of organisms into convenient categories or groups on the basis of their similarities and differences in certain easily observable but fundamental characters. Then a hierarchy of categories is raised keeping in mind the affinities or relationships of various groups. Therefore, categories or taxonomic categories represent distinct biological entities and not merely morphological aggregates. The various categories are kingdom, phylum (or division in plants), class, order, family, genus and species.

4. **Nomenclature** (L. *nomen*– name, *calare*– call). It is the science of providing distinct and proper names to organisms so that they can be easily recognised and differentiated from others. Through nomenclature each organism is given a two word name, **generic** and **specific**, *e.g.*, *Mangifera indica* (Mango).

5. **Identification**. Identification is the finding of correct name and place of an organism in a system of classification. Identification is done with the help of keys. This is carried out by determining similarity with already known organisms. Suppose there are 3 types of animals belonging to different species— x, y, z. An animal *t* is found in a locality being surveyed. It is found to resemble the species *y*. The finding that the animal *t* belongs to species *y* is its identification.

6. **Key**. It is a list of alternate characters arranged in such a manner that by selection and elimination one can easily identify an organism as to its name and position.

SYSTEMATICS

Systematics is a branch of Biology that deals with cataloguing plants, animals and other organisms into categories that can be named, remembered, compared and studied. Study of only one organism of a group provides sufficient information about the remaining members of that group. Scientists connected with the study of systematics are called **systematists** or **taxonomists**. The terms systematics, taxonomy and classification are often held as synonyms but technically they carry different meanings. Simpson, (1961) has defined systematics as the branch of biology that deals with the **diversity of organims** at every level of classification. Taxonomy, systematics or classification of organisms is based on the study of their comparative morphology (form, external and internal structure), cytology, embryology fossil relatives, biochemical analysis and ecological relationships. The knowledge is required by all biologists working in different fields, *e.g.*, agriculture, forestry, industry, ecology, medicines, genetics, physiology, etc. It also helps in developing evolutionary relationships, with or without the help of taxonomic studies of fossils.

History. Early classifications were concerned entirely for easy identification of useful and harmful plants and animals. Hippocrates (460–377 BC, father of medicine) and Aristotle (384–322 BC, father of zoology) arranged animals on the basis of habitat into aquatic, terrestrial, aerial animals. On the basis of single character, Greek scholars divided animals into four major groups— insects, birds, fishes and whales. Theophrastus (father of botany, 370–285 BC) divided plants on the basis of form, texture and habit into four groups— trees, shrubs, undershrubs and herbs. He described 480 plants in his book 'Historia Plantarum'.

Pliny the Elder (28–79 A.D.) introduced the first system of artificial classification. His

book, *Historia Naturalis* (c75 AD), mentions over 1,000 economic plants with about 2,000 items. More and more organisms were discovered and named. **John Ray** (1627–1705), English naturalist, described about 18,600 plants in three volumes 'Historia Generalis Plantarum' between 1686–1704. The naturalist introduced the word "**species**" in its present sense for the first time. **John Ray** defined species as an assemblage of individuals with similar parentage and having ability to pass the parental traits to the offspring. Swedish naturalist Carolus Linnaeus developed the scientific system of naming species. It is known as binomial system of nomenclature. Linnaeus described 5900 species of plants in his book *Species Plantarum* (1753) and, 4326 species of animals in *Systema Naturae* (1758). The word systematics is derived from Latin word 'systema' which means systematic arrangement of organisms. Linnaeus used *systerma Naturae* as the title of his book.

Right from Aristotle to Linnaeus, every systematist employed limited number of traits for classification of organisms. Therefore, the systems proposed by them remained artificial. Later on with increased indepth study of various biological domains, more and more characters were taken into consideration by taxomonists. It brought out natural affinities amongst organisms. This represented the phase of **classical taxonomy** which produced **natural systems of classification**. A modification of this system is **numerical taxonomy** or **phenetics** which came into existence during 1950s. Simultaneously biologists began to find out evolutionary and genetic relationships. This resulted in development of **phylogenetic classification** or **cladistics** (Gk. *klados*– branch, L. *clados*– branch). In cladistics organisms are arranged in historical order in which they evolved as branches of the parent stock. This phase is known as **new systematics** or biosystematics. Father of new systematics is Sir Julian Huxley (1940).

Basics of Systematic Study

1. **Description (Characterisation).** The organism to be studied is described for all its morphological and other characteristics.
2. **Identification.** Based on the studied characteristics, the identification of the organism is carried out to know whether it is similar to any of the known group or taxa.
3. **Classification.** The organism is now classified on the basis of its resemblance to different taxa. It is possible that the organism may not resemble any known taxa or groups. A new group or taxon is raised to accomodate it.
4. **Nomenclature.** After placing the organism in various taxa, its correct name is determined. If the organism is new to systematics, it is given a new name based on rules and conventions of nomenclature.

Classical Taxonomy

It is taxonomy based on observable morphological characters with normal individuals considered to be expression of the same while their variations are believed to be imperfect expressions. Classical taxonomy originated with Plato followed by Aristotle (Father of Zoology), Theophrastus (Father of Botany) upto Linnaeus (Father of Taxonomy) and his contemporaries.

1. Species are delimited on the basis of morphological characters.
2. Only a few characters are employed for classification.
3. A few individuals or their preserved specimens are used for study. It is called **typological concept**.

4. Species are believed to be static or immutable.
5. Species is centre stage of study. Its sub-units are not important.

New Systematics or Modern Taxonomy

The term new systematics was coined by **Julian Huxley (1940)**. New systematics is the systematic study which takes into consideration all types of characters including those from classical morphology, anatomy, cytology, physiology, biochemistry, ecology, genetics, development (embryology), behaviour, etc. of the whole population instead of a few typological specimens. In contrast **classical systematics** is based on the study of mainly morphological traits of one or a few specimens with supporting evidences from other fields. New systematics is also called **population systematics** and **biosystematics**. It strives to bring out evolutionary relationships amongst organisms.

1. New systematics is based on the study of all types of variations in the species.
2. Alongwith morphological characters, other investigations are also carried out to know the variety of traits.
3. Delimitation of species is carried out on the basis of all types of biological traits. It is also called biological delimitation.
4. Traits indicating primitiveness and advancement are found out.
5. Inter-relationships are brought out.
6. Species are considered dynamic.

Differences between Classical Taxonomy and Modern Taxonomy

Classical Taxonomy	*Modern Taxonomy*
1. It deals with morphospecies.	1. It deals with biological species.
2. It has a typological concept.	2. It has a population or biosystematic concept
3. Species is considered to be static.	3. Species is considered to be dynamic
4. It does not study evolution and inter-relationships of species.	4. It studies primitiveness, advancement and inter-relationships of species

NOMENCLATURE

Two types of names have been given to organisms, common and scientific.

Vernacular or Common Names

They are names given to the organisms in a particular language and region of the world. There are several types of names like English, Hindi, Gujarati, Marathi, Bengali, Tamil, etc. The names have been in use since times immemorial. New names are added whenever outside organisms are introduced into the area. Vernacular names are usually single word names and are hence **uninomial**.

The vernacular names have their uses : (i) They are based on some minor or major characteristics of organism, *e.g.*, Kandiali (after the occurrence of spines), Dodhak (after milky latex). (ii) They are brief. (iii) The residents of an area become familiar with them since their childhood. (iv) The vernacular names are easier to pronounce and remember by the residents of an area. Even then the vernacular names cannot be used by biologists due to the following reasons :

1. All organisms do not occur in an area.

2. Many organisms occurring in a particular area have not been given common names because they are either microscopic or are unimportant to human affairs.

3. Certain common names have no significance. Rather they are misleading, *e.g.*, Love-in-a-Mist (*Nigella damascena*), Hen-and-Chicken (*Sempervivum soboliferum*), Forget-Me-Not (*Myosotis sylvatica*), Widow's Tears (*Tradescantia* or *Rhoeo* species), Yesterday-Today-Tomorrow (*Brunfelsia hopeana*).

4. Some common names have incorrect meaning, *e.g.*, Silver Fish, Jelly Fish, Cuttle Fish, Star Fish. They belong to different phyla and have no relationship with true fishes. Silver fish is not even aquatic.

5. Common names cannot be used in communications amongst scientists of even the different regions of same country because the same organism has different local names in different parts. For example, Rose is called gulab in Hindi, golap in Bangla and Rojapo in Tamil. Butterfly is titli in Hindi, prajapati in Bangla and vannathu poochi in Tamil.

6. Sometimes a single organism is known by several names in the same language, *e.g.*, Water Lily has 81 Dutch names, 44 French names and 15 English names. Likewise, Prickly Poppy has 8 Hindi names.

7. Different regions can have opposing names. Corn is Maize in Commonwealth countries while it implies wheat and other grains in U.S.A.

8. A single name is often used for two or more species. Touch-me-not is the name for both *Impatiens balsamifera* (Balsam) and *Mimosa pudica* (Sensitive Plant). Dodhak is the name of many plants that possess milky latex *e.g.*, *Euphorbia, Sonchus, Launaea*, etc.

9. A wrong common name cannot be easily corrected.

Scientific or Technical Names

A scientific name is the one which is given by biologists and is understood to represent a particular organism in every part of the world. Scientists ensure that a name being given by them had not been used earlier for any other organism. The system of providing scientific and technical names is known as binomial nomenclature.

Binomial Nomenclature

The system was developed by Linnaeus (*Philosophia Botanica*, 1751). The technical names recognised internationally are the ones given by Linnaeus in "*Species Plantarum*" (1753) and the 10th edition of his book "*Systema Naturae*" (1758). *Binomial nomenclature is the system of providing organisms with appropriate and distinct names consisting of two words, first generic and second specific.* The first or generic word is also called genus. It is like a noun and its first letter is written in capital form. The second word or specific epithet represents the species. It is like an adjective. Its first letter is written in small form except occasionally when it denotes a person or place. To the two word name is appended the name of taxonomist who discovered the organism and provided it with its scientific name, *e.g.*, *Ficus bengalensis L., Mangifera indica Linn., Homo sapiens* Linneaus. The name of taxonomist can be written in full or in abbreviated form. There are several technical names which have three words, *e.g.*, *Homo sapiens sapiens, Acacia nilotica indica, Gorilla gorilla gorilla.* Here the first word is generic,

Carolus Linnaeus (1707–1778)

the second specific while the third word represents variety (mostly in botanical literature) or subspecies (mostly in zoological literature).

Rules of Binomial Nomenclature

There are five codes of nomenclature : (i) International Code of Botanical Nomenclature (ICBN), (ii) International Code of Zoological Nomenclature (ICZN), (iii) International Code of Bacteriological Nomenclature (IC Bac N), (iv) International Code of Viral Nomenclature (ICVN) and (v) International Code of Nomenclature for Cultivated Plants (ICNCP). International conferences are held from time to time to update the codes and resolve the controversies, if any. The rules of nomenclature framed under these codes as well as the rules set by Linnaeus are as follows :

1. Each organism is given only one name consisting of two words, generic and specific.

2. Though the codes are separate for plants, animals, bacteria, etc. and the same generic name can be given to different organisms belonging to these domains, it should be avoided. However the same specific name can be given to organisms belonging to different genera. Two species belonging to the same genus cannot have similar specific names.

3. The generic name is written first. It is followed by specific epithet and then the name of the discoverer in full or in abbreviation.

4. The specific epithet can be single or compound. Usually it begins with a small letter.

5. The scientific name is printed in italics. It's two words are separately underlined in handwritten description. An exception is made when the biological name is written as title of paragraph.

6. The name of the author is kept in Roman script.

7. The original names were taken from Latin and Greek languages. New names are now derived either from Latin language or are latinised. This is because Latin language is dead and, therefore, it will not change in form or spellings with the passage of time.

8. Barring obvious error or misprint, a scientific name retains its original spellings.

9. No names are recognised prior to those used by Linnaeus in 1753 for plants in "*Species Plantarum*" and in 1758 for animals in the 10th edition of "*Systema Naturae*".

10. The names of families and subfamilies should be based on name of type genus.

11. The names of subfamilies, families and other categories are not printed in italics. They can, however, be written in bold letters.

12. When a species is transferred or revised the name of the original worker is retained but in parenthesis, *e.g.*, *Syzygium cumini* (L) Skeels.

13. In publishing a new name the type specimen of the material is kept.

14. A new scienfitic name is thought of on the basis of its characteristic, a personality or place. The selected name is such that it has no resemblance with any previously published name.

Advantages of Scientific Names

(i) Every species has a single and specific name consisting of two (or rarely three) words. (ii) Every organism known to science has been provided with a scientific name irrespective of its importance. (iii) There is no possibility of any change in the spellings of a scientific name as the latter has been derived from dead Latin language. (iv) The names are of universal application for all the countries and the languages. (v) They are generally descriptive. (vi) The names indicate relationship of a species with others present in the same genus. (vii) They are comprehensive and are easier to recollect. (viii) A wrong name can

easily be corrected. (ix) A newly discovered organism can be easily provided with a new scientific name

Revision of Group

It is the grouping of species into distinct taxa on the basis of their resemblances and differences, development of complexity or simplicity and hence evolutionary relationships. First of all criteria are selected for delimiting a species. In case of sexually reproducing organisms, interbreeding is used as the basic criterion. In case of others, morphology, physiology, cytotaxonomy and molecular biology including DNA-matching is resorted to. The species are then grouped into higher taxonomic categories on the basis of certain common features called **correlated characters**.

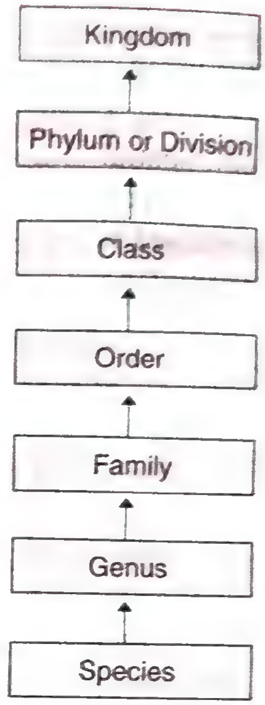


Fig. 1.1. Taxonomical Hierarchy showing arrangement in ascending order

TAXONOMIC CATEGORIES (Taxonomic Hierarchy)

It is also called Linnaean hierarchy because it was first proposed by Linnaeus. *Hierarchy of categories is the classification of organisms in a definite sequence of categories* (**taxonomic categories**) *in a descending order starting from kingdom and reaching upto species or an ascending order from species to kingdom*. The number of similar characters of categories decreases from lowest rank (species) to highest rank (Kingdom, Fig. 1.1). The hierarchy includes seven **obligate categories**— kingdom, division or phylum, class, order, family, genus and species. The categories are arranged in descending sequence keeping the kingdom at the top. In order to make taxonomic position of species more precise, certain categories have been added to this list. They are called **intermediate categories**, *e.g.*, subkingdom, superphylum or superdivision, subdivision, superclass, subclass, superorder, suborder, superfamily, subfamily, tribe, subspecies, variety, etc. Hierarchical classification of some of organisms is given in table 1.1.

Table 1.1. Organisms with their Taxonomic Categories

Common Name	Scientific Name	Genus	Family	Order	Class	Phylum/ Division	Phyla/ Kingdom
Human	*Homo sapiens*	*Homo*	Hominidae	Primata	Mammalia	Chordata	Animalia
Dog	*Canis familiaris*	*Canis*	Canidae	Carnivora	Mammalia	Chordata	Animalia
Housefly	*Musca domestica*	*Musca*	Muscidae	Diptera	Insecta	Arthropoda	Animalia
Mango	*Mangifera indica*	*Mangifera*	Anacardiaceae	Sapindales	Dicotyledonae	Angiospermae	Plantae
Wheat	*Triticum aestivum*	*Triticum*	Poaceae	Poales	Monocotyledonae	Angiospermae	Plantae
Tulsi	*Ocimum sanctum*	*Ocimum*	Lamiaceae	Lamiales	Dicotyledonae	Angiospermae	Plantae

There are seven obligate categories and some intermediate categories. The seven obligate categories are as follows :

1. **Species***. Species (used both as singular and plural) is a natural population of individuals or group of populations which resemble one another in all essential morphological and reproductive characters so that they are able to interbreed freely and produce fertile offspring. Mango is species *indica* of genus *Mangifera* (*Mangifera indica*). Potato is species

*Term species was coined by John Ray.

tuberosum of genus *Solanum* (*Solanum tuberosum*). Lion's species is *leo* of genus *Panthera* (*Panthera leo*) while Tiger's species is *tigris* of genus *Panthera* (*Panthera tigris*). Each species is also called genetically distinct and reproductively isolated natural population. Mayr (1964) has defined species as "*a group of actually or potentially interbreeding populations that are reproductively isolated from other such groups*". However there are two objections for using interbreeding as a sole criterion for delimitation of a species.

(i) Occasional hybrids occur in nature due to breakdown of mechanical, physiological, spatial and seasonal barriers between species. Interspecific hybrids have been obtained since ages artificially by man, *e.g.*, mule. Hybrids between closely related species are often obtained in captivity. These hybrids are generally sterile, but some are fertile as well. A few examples are given below :

(a) Mule (sterile)— Female horse and male donkey
(b) Hinny (sterile)— Male horse and female donkey
(c) Tigon (fertile)— Male tiger and female lion
(d) Liger (fertile)— Male lion and female tiger

(ii) Sexual reproduction is absent in procaryotes and some protists. In such cases and fossils, morphological differences, cytotaxonomy and chemotaxonomy are resorted.

Principles for Delimiting a Species. (i) The different members of a species whether morphologically similar or dissimilar are able to interbreed freely and produce fertile offspring. (ii) All the members whether present in one population or different populations found in remote areas of the globe are derived from a common ancestor. (iii) The members resemble one another more than they resemble individuals of any other species. (iv) There is a complete anatomical similarity. (v) All the members of a species have similar karyotype (cytotaxonomy)— there is similarity in the number, size, shape and behaviour of meiotic chromosomes. (vi) All the individuals of a species contain similar genetic material. (vii) There is a broad similarity in morphological characters. (viii) At the molecular level there is similarity in the types of proteins, enzymes, hormones and other biochemicals (chemotaxonomy).

2. **Genus**. It is a group or assemblage of related species which resemble one another in certain correlated characters. **Correlated characters** are those similar or common features which are used in delimination of a taxon above the rank of species. All the species of genus are presumed to have evolved from a common ancestor.

It is not essential for a genus to have several species. There are genera which have only one species. They are called **monotypic**. Others are known as **polytypic**. Thus the genus *Solanum* has a large number of closely related species, *e.g.*, *S. tuberosum* (Potato), *S. melongena* (Egg Plant, Brinjal), *S. nigrum* (Black Night-shade), *S. surratense*

Similarly Lion, Tiger, Leopard, Jaguar are closely related species which have been placed in the genus *Panthera*. The animals are respectively named as *Panthera leo*, *P. tigris*, *P. pardus* and *P. onca*. These ferocious animals are related with some differences to cats included in the genus *Felis*, *e.g.*, *F. domestica* (Common Cat), *F. bengalensis* (Leopard Cat), *F. marmorata* (Marbled Cat), *F. chaus* (Jungle Cat), *F. viverrina* (Fishing Cat) and *F. temminki* (Golden Cat).

3. **Family**. It is taxonomic category which contains one or more related genera. All the genera of a family have some common features or correlated characters. They are separable from genera of a related family by important and characteristic differences in both vegetative and reproductive features. Thus the genera of cats (*Felis*) and leopard (*Panthera*) are

included in the family **felidae**. The members of family felidae are quite distinct from those of family **canidae** (dogs, foxes, wolves). Similarly, the family **solanaceae** contains a number of genera like *Solanum*, *Withania*, *Datura*, *Petunia* and *Nicotiana*. They are distinguishable from the genera of the related family **convolvulaceae** (*Convolvulus*, *Ipomoea*).

4. **Order**. The category includes one or more related families. Thus the family solanaceae is placed in the order **polemoniales** alongwith four other related families (convolvulaceae, boraginaceae, hydrophyllaceae and polemoniaceae). Similarly, the families felidae and canidae are included under the order **carnivora** alongwith hyaenidae (hyaenas) and ursidae (bears). The category of order and higher ranks are differentiated on the basis of **aggregate of related characters.**

5. **Class**. A class is made of one or more related orders. For example, the class **dicotyledoneae** (dicotyledonae, dictoyledons) of flowering plants contains all dicots which are grouped into several orders (*e.g.*, rosales, passiflorales, polemoniales, sapindales, ranales, etc.) Likewise, class **mammalia** of animals includes all mammals which range from bats (order chiroptera), kangaroos (order marsupialia), rodents (order rodentia), whales (order cetacea), carnivores (order carnivora) to great apes and man (order primata).

6. **Division* or Phylum**. It is a category higher than that of class. The term phylum is used for animals while division is commonly employed for plants. A division or phylum is formed of one or more classes. The phylum **chordata** of animals contains not only the class mammalia but also aves (birds), reptilia (reptiles), amphibia (amphibians), cyclostomata, chondrichthyes, osteichthyes (fishes), etc. The division **spermatophyta** in plants has similarly seven classes of gymnosperms and two classes of angiosperms.

7. **Kingdom**. It is the highest taxonomic category. All plants are included in kingdom plantae while all animals belong to kingdom animalia.

Taxon (plural– taxa, Gk. *taxis*– arrangement)

It is a unit in classification which may represent any level of grouping of organisms based on certain easily observable common characteristics like Maize (species), roses (genus), grasses (family), conifers (order), dicots (class), seed plants (division), etc (**Table 1.2**). The term was introduced for the first time by ICBN during 1956. Mayr (1964) has defined taxon to be a *taxonomic group of any rank that is sufficiently distinct to be worthy of being assigned to a definite category*. Simpson (1961) recognises taxon to be a group of real organisms recognised as a formal unit at any level of hierarchical classification.

Differences between Taxon and Category

Taxon	*Category*
1. It deals with objects.	1. It deals with ranking.
2. Taxon is real.	2. Category is an abstract term.
3. It may belong to any ranking.	3. It belongs to one particular ranking.

There is some confusion in the use of taxon and category. Bryophyta is a taxon while division is a category. Similarly *Zea mays* is a taxon while species is a category. Thus while category represents an abstract term, taxon represents the real organisms. Certain common names represent species while other represent genus, family, order, class or phylum.

* Botanists use the term Division instead of Phylum.

Table 1.2

SOME COMMON NAMES AND THEIR CATEGORY* LEVEL

Phylum	*Class*	*Order*	*Family*	*Genus*	*Species*
Flat worms	Fishes	Bats, Monkeys	Tortoises	Wolves	Man
Round worms	Birds	Frogs and Toads	Cobras	Hooded Cobras	Dog
	Insects	Turtles	Eagles	Crows	Horse
	Millipedes	Snakes	Cranes		Domestic Cat
	Centipedes	Lizards	Woodpeckers		Domestic Cow
	Snails	Butterflies	Ducks		Tiger
		Beetles	Elephants		Lion
		Spiders	Bears		Indian Elephant
		Scorpions	Deer		Indian Peacock
		Earthworms	Ants		House Sparrow
			Mosquitoes		House Crow
Algae	Flowering plants	Mushrooms	Grasses	Citrus	Rice
(red, brown,	Mosses	Yeasts	Orchids	Eucalpyptus	Potato
green)	Ferns		Gourds	Pines	Neem, Banyan
	Conifers		Bracket fungi		Coconut, Mango
			Palms		Baker's Yeast

TAXONOMICAL AIDS (TOOLS FOR STUDY OF TAXONOMY)

Techniques, procedures and stored information that are useful in identification and classification of organisms are called taxonomic aids. They are required because taxonomic study of plants, animals and other organisms are basic to almost all branches of biological studies for their proper identification and finding their relationships with others. Identification of organisms requires both field studies and intensive laboratory studies. A prime source of taxonomic studies is the collection and preservation of actual specimens of plants and animals. The information about habitat, habits and other observable traits is also recorded alongwith the specimen.

Herbarium, Botanical Gardens, Museum, Zoological Parks (Zoos) and key are important tools used in identification of plants and animals.

I. HERBARIUM

Herbarium is a place where dried and pressed plant specimens, mounted on sheets are kept systematically according to a widely accepted system of classification. Herbarium is a repository or store house for future use. Every institute teaching botany, school, college or university, has a small or large herbarium. Very large herbaria are maintained by botanical gardens and institutes connected with plant systematics.

Every student of botany is required to collect plant specimens and prepare herbarium sheets.

Equipment. Digger and pruning knife, sickle with long handle, vasculum, polythene bags, magazines or newspapers, blotting papers, plant press, field notebook, herbarium sheets, glue, labels, small transparent polythene bags.

Method of Specimen Collection and Mounting. An area is selected for botanical excursion. It is preferable to visit the same site in different seasons. For herbaceous species the entire plant with intact parts is collected. For others, shoots having flowers, leaves and fruits are selected and cut with the help of pruning knife. Sickle with long handle is used if the desired twigs are present at a height. Diggers are used to obtain underground parts like root system, tuber, bulb, corm, rhizome, etc. The collected material can be placed in polythene

bags or vasculum. Vasculum is a special box with a length of 45–60 cm, depth of 25 cm and width of 20 cm. It keeps the material airtight and prevents wilting till the same is placed inside drying sheets. The collected specimens are spread over magazine or newspaper sheets. Care is taken to spread the leaves properly and to separate the petals so as to expose the essential organs. If the specimen is longer than the sheet, the same can be gently bent in *n* or *w* form. Some of the flowers are kept open so as to facilitate examination of floral parts. Some of the leaves are bent to expose dorsal (under) surface. Magazine and newspaper sheets are now put inside the press. Plant press consists of two boards with straps for tightening. Details of collection should be jotted down in the field notebook. For this every collected material is given a number. The details include plant size, branching, root system and specialised underground organ, flower colour, topography and date of collection. Preservative liquid used for storing fleshy organs is FAA (10 ml. formalin, 5 ml. glacial acetic acid, 50 ml. of 95% ethyl alcohol and 35 ml. of water).

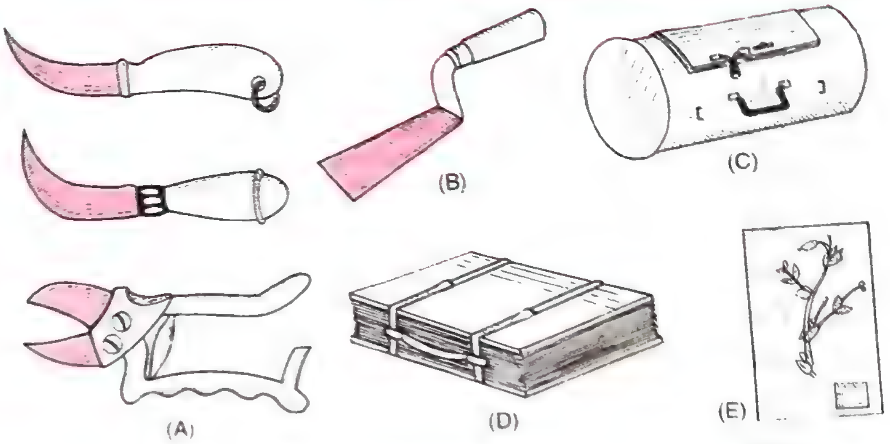


Fig. 1.2. Tools for plant collection. A, cutters, B. digger (khurpi). C. vasculum D. plant press. E. herbarium sheet.

After 24 hours, the sheets are changed. Blotting papers can be used. They help in quick drying. Two or three changes are required at an interval of 3–5 days for complete drying of the specimens. Some workers prefer to maintain the specimens in drying sheets for 1–2 months. Meanwhile herbarium sheets are selected. They are available in different colours. The general size is 30 × 45 cm. It is slightly shorter in American herbaria (29 × 41 cm). Good quality glue is applied to the back of dried specimen and the same is placed over the herbarium sheet. Students prefer to use cellotape but the same should be avoided as its retaining power is little. Labels (7 × 12 cm) are fixed over the lower right hand corner of the sheets. Information about the family, genus, species, author, plant characteristics, area, date and collector's name is given over each label. The sheets are now covered with polythene or tissue paper in order to avoid tearing of delicate parts. Heavy parts like fruits or seeds are kept in a paper or polythene packet and attached to the sheet. Herbarium sheets are arranged according to a system of classification, *e.g.*, Bentham and Hooker in India. The specimens belonging to the same genus are often packed together and placed in steel cabinets. The specimens are treated with 0.1% mercuric chloride for preventing fungal attack. DDT, naphthalene and carbon disulphide are also used as pesticides. Repelling chemicals (*e.g.*, Moth or naphthalene balls) are placed alongwith herbarium sheets for protection against insects.

Uses of Herbarium. (i) It provides information about the local flora as well as flora of distant areas. (ii) Herbaria are used for correct and authentic identification of unknown plants. (iii) It provides information about the ecology of different places. (iv) The information is useful in locating wild varieties and relatives of economically important plants. The same is helpful in breeding programmes for evolving newer and better varieties. (v) It depicts the

morphological variations found in species. (vi) Information is obtained as to the season of flowering of various plants. (vii) It serves as a quick referal system for taxonomic studies.

Important Herbaria

	Name	Number of Herbarium Specimens
1.	Royal Botanical Gardens, Kew (London) (Largest herbarium)	6.5 million
2.	Museum of Natural History (Paris)	Over 6.0 million
3.	Conservatoire at Jardin Botaniques de Geneve (Geneva)	Over 5.0 million
4.	V.L. Komarov Botanical Institute of Azerbaijan	4.0 miiiion
5.	New York Botanical Garden (New York)	4.0 million
6.	Central National Herbarium (Indian Botanical Gardens) Sibpur, Kolkata, India	2.0 million
7.	Madras Herbarium, Coimbatore (MH), India	1,50,000
8.	Herbarium of National Botanical Research Institute, Lucknow, India	80,000

Identification of Species

Manuals. floras, monographs, catalogues and keys are used in identification of species.

Manual. It is handy book containing instructions as to occurrence, collection and identification of species found in a particular area.

Flora. It is a book containing information as to the habitat, climate, seasonal changes, distribution, description and index of plants found in a specific area.

Monograph. It is treatise having all information about a particular taxon like family or genus.

Catalogue. It is list or register that enumerates methodically all the species found in a particular place, often with brief description aiding identification.

Key. It is booklet containing list of characters and their alternates which are helpful in identification of various taxa— class, order, family, genus and species.

II. BOTANICAL GARDENS

Botanical gardens are sufficiently large sized tracts where plants of different types and areas are grown for scientific and educational purposes. The first real botanical garden was developed by Theophrastus (370–285 B.C.). Of course, gardens were part of Indian, Chinese and Roman cultures. "Hanging Gardens" of Babylon were considered to be wonders of ancient times. Modern day botanical gardens contain besides out-door plants, green houses, library, research laboratory and herbarium with documented collection of various taxa. There is an International Association of Botanical Gardens (established in 1962) which coordinates research and exchange of plant materials. The important functions of botanical gardens are: (i) Growing important plants of local flora. (ii) Keeping record of local flora. (iii) Providing living plant material for systematic work. (iv) Supplying seeds and material for different aspects of botanical research. (v) Growing and maintaining rare and endangered plants.

Establishment of modern botanical gardens began in 16th century— Pisa, Italy (1543), Padua Gardens, Italy (1545), Jardin de Jussieu, France (1593) and Leiden, Netherland (1594). Some major botanical gardens of the world are :

1. **Main Botanical Garden, Moscow**. Largest garden, spread over an area of 900 acres.

2. **Bundes Garden, Vienna**. It is spread over an area of 400 acres.

3. **Royal Botanical Garden, Kew (London)**. It has an area of 300 acres but grows a very large number of plants.

4. **Kebun Raya (Botanical Garden) Bogor, Java**. Spread over an area of 200 acres, the garden has a section with **virgin rain forest**.

5. **Arnold Arboretum, Boston (U.S.A.)**. It supports a very large number of bonsai trees and green houses.

6. **Indian Botanical Garden Sibpur, Kolkata**. It is the largest botanical garden of Asia spread over an area of 273 acres which is famous for its Great Banyan tree, Palm house, Succulent plants, Indian grasses, Water lilies, etc.

7. **Lloyd Botanical Garden, Darjeeling**. Occupying an area of only 40 acres, the garden has a large number of terrestrial and epiphytic orchids, a large number of conifers, cycads, ferns and alpine plants.

8. **National Botanical Garden, Lucknow** (Sikander Bagh). The garden has an area of 70 acres. It grows a large number of diverse plants, palms, ferns, medicinal plants, cacti and ornamentals. The garden has laboratories of different fields of botanical research.

Two famous botanical gardens of South are Botanical Garden, Ootacumand and Lalbag Gardens, Bangalore.

III. MUSEUM

What is Museum ? The word museum comes from the Greek word *mouseion*. In ancient Greece the mousein was the temple of the *Muses*, the goddesses of arts and sciences. Museum is an institution where artistic and educational materials are exhibited to the public. The materials available for observation and study are called a **collection**. A collection may include scientific specimens, works of art and exhibits and information on history or technology.

Functions of Museums. Museums perform the following functions :

1. **Acquisition of Materials.** Every new object that a museum adds to its collection is called an acquisition. Museums acquire objects in several ways, of which field collection is one of the most useful. The scientists and technicians go outside to gather specimens and data on a particular subject which are within the scope of the museum.

2. **Recording of materials.** Each acquisition is listed carefully by specialist staff. As soon as objects are received, the data, the source, the method of acquisition and other available informations are entered in the record register.

3. **Preservation of Materials.** The primary purpose of museums is to preserve selected objects. Curators (persons incharge of museums) know that no specimens will last forever. What museums undertake to do is to prolong the life time of the objects. Preservation in a museum consists of two steps. (i) specimens must be put into a condition that checks deterioration. (ii) the specimens must be protected.

4. **Research.** One important use of museum is to extract as much knowledge as possible from the specimens. Many museums publish scholarly journals, series of papers and books to make available the results of research on their collection.

5. **Exhibition of Materials.** Various members of the museum staff prepare the acqui-

sitions for exhibition. The specimens selected for exhibition are put on view in numerous ways. The choice of approach and technique depends largely on the purpose of exhibit.

6. **Education.** A number of universities conduct some courses in certain subjects at museums in order to take advantage of the collection. Thus museums help in spreading education.

Following Museums are Important from Natural Science Point of View

1. Natural History Museum, London.
2. United States National Museum, Washington.
3. La Plata Museum, La Plata, Arg.
4. Field Museum of Natural History, Chicago.
5. Zoology Museum, Amsterdam, Neth.
6. Sugarlands Museum, Great Smoky Mountains National Park in eastern Tennessee.
7. Rock Creek Nature Center, Washington.
8. National Museum of Anthropology, Mexico City.
9. Mus éé de l'Homme, Paris.
10. Anthropological Museum, Andaman and Nicobar islands.
11. Forest Museum, Andaman and Nicobar Islands.
12. National Museum of Natural History, Delhi.
13. Prince of Wales Museum, Mumbai.
14. Maharaja Sawai Man Singh (II) Museum, Jaipur.
15. Indian Museum, Kolkata.

IV. ZOOLOGICAL PARKS (ZOOS)

A zoo is a place where various living animals are kept within enclosures, displayed to the public and may be used for study. Animals may also be bred. Infact concept of zoo has changed. *Instead of Zoos*, **Zoological Parks** or **Zoological gardens** *are established* where high standard of care is observed and the animals live under more natural conditions. The animals provide better recreation to the visitors.

The Role of Zoological Parks in Wildlife Conservation. The regular zoo movement in India, began in the year 1855 when the first zoo was set up in Chennai. In the zoological parks animals enjoy protection, fine sun-shine, fresh air and above all ample open space to play about. They have now become repositories of threatened wildlife and a store house of the knowledge on animal behaviour, their breeding habits, etc. Zoological park is the place where they are assured of food, medical care and treatment and where they also feel safe from their natural enemies. The establishment of zoological parks helps in providing knowledge about different native and exotic wild mammals, birds, reptiles, fish and flora to the public in general and school children in particular. Zoological parks are very useful in spreading knowledge on the wildlife wealth of the country.

Zoological parks all over the world have been involved in the rescue of many species threatened with extinction. Our country has made good progress in the rehabilitation of some endangered species. The Crocodile Rehabilitation Project is being run by the FAO to rehabilitate crocodiles. Similarly the Himalayan Musk Deer is being bred at Kufri. Attempts have also been made for preserving other species like Blackbuk, Sambar and Spotted Deer. Similar projects for pheasants and partridges are under way. Conservation efforts have been made over the world by breeding birds and mammals in parks and releasing them in free state as

in case of the Great Indian Bustard, Houbara Bustard, Hawaiian Goose, European Bison, etc. The zoological parks, therefore, are playing an important role in wildlife conservation.

Zoos of India. The abbreviation "zoo" was first used for the **London Zoological Gardens**, which opened for scientific study in 1828 and to the public in 1847. The number of major animal collections open to the public around the world now exceeds 1,000, around 80 percent of them in cities.

The Central Zoo Authority of India (CZA) manages all Zoos in India.

1. Alipore Zoological Gardens, Kolkata
2. Allen Forest Zoo, Kanpur
3. Arignar Anna Zoological Park (Vandalur Zoo), Chennai
4. Birsa Munda Jaivik Udyan, Ranchi
5. Guwahati Zoo, Assam, India
6. Indira Gandhi Zoological Park, Visakhapatnam, Andhra Pradesh
7. Jawaharlal Nehru Biological park, Bokaro Steel City
8. Jaipur Zoo, Jaipur
9. Jijamata Udyaan, Mumbai, Maharashtra
10. Nawab Wajid Ali Shah Zoological Garden, Lucknow
11. Madras Crocodile Bank Trust
12. Mahendra Chaudhury Zoological Park, Chhatbir, Punjab
13. Marble Palace Zoo, Kolkata
14. Mysore Zoo, Karnataka
15. Nandankanan Zoo, Orissa, India
16. National Zoological Park, Delhi
17. Nehru Zoological Park, Hyderabad, Andhra Pradesh
18. Pt. G.B. Pant High Altitude Zoo, Nainital, Uttarakhand, India
19. Padmaja Naidu Himalayan Zoological Park, Darjeeling
20. Parassinikkadavu Snake Park
21. Sakkarbaug Zoological Garden, Junagadh, Gujarat
22. Sanjay Gandhi Jaivik Udyan, Patna
23. Sepahijala Zoo, Tripura
24. Sree Venkateswara Zoo, Tirupati, Andhra Pradesh
25. Rajiv Gandhi Zoological Park, Pune, Maharashtra
26. Trissur Zoo, Thrissur, Kerala
27. Tilyar Zoo, Rohtak
28. Thiruvananthapuram Zoo, Trivandrum, India

V. KEY FOR IDENTIFICATION

Key or taxonomic key is an artificial analytic device having a list of statements with dichotomic table of alternate characteristics which is used for identifying organisms. Usually a couplet or two contrasting characters are used. The one present in the organism is chosen while the other is rejected. Each statement of the key is called **lead**. Separate taxonomic keys are used for each taxonomic category like family, genus and species. Two types of keys are commonly used— **indented** (or yolked) and **bracketed**.

Indented Key (Yolked Key). The key contains a sequence of choices between two or more characteristics. By careful selection of character at each subdivision the exact name of the organism can be arrived at.

Bracketed Key. The key uses contrasting characters like the indented one but they are not separated by intervening subdividing characters. Instead, each character is given a number in brackets.

We can take the example of seven genera of family Ranunculaceae— (i) *Anemone*. Leaves alternate or radical, flowers subtended by involucre, carpels 1-ovuled, fruit achenes. (ii) *Ranunculus*. Leaves alternate or radical, flowers not subtended by involucre, carpels 1-ovuled, fruit achenes. (iii) *Clematis*. Leaves opposite, compound, petals absent, sepals 4, carpels uniovuled and fruit achenes. (iv) *Naravelia*. Leaves opposite, compound, terminal leaflets modified into tendrils, sepals and petals present, carpels 1- ovuled, fruit achenes. (v) *Nigella*. Flowers regular, carpels united at base, many ovuled, fruit follicles. (vi) *Aconitum*. Flowers irregular, posterior sepal enlarged to form hood, carpels free, many ovuled, fruit follicles. (vii) *Delphinium*. Flowers irregular, posterior sepal enlarged to form spur, carpels free, many ovuled, fruit follicles.

Indented Key	**Bracketed Key**
Carpels 1-ovuled, fruit achenes	(1) Carpels 1-ovuled, fruit achenes ......(2)
Leaves opposite, compound	(1) Carpels many ovuled, fruit follicles ..(5)
Sepals 4, petaloid, petals 0, no leaflet tendrils ....*Clematis*	(2) Leaves opposite, compound ....(4)
Sepals as many as petals, 4—5, terminal leaflet modified into tendrils .....*Naravelia*	(2) Leaves alternate, radical ....(3)
	(3) Flowers subtended by involucre ...... *Anemone*
Leaves alternate or radical	(3) Flowers without involucre ......*Ranunculus*
Flowers with involucre ....*Anemone*	(4) Sepals 4, petaloid, petals 0, no leaflet

Fish— Presence of scales, streamlined body, gills, fins but absence of limbs and pinnae.

Snake— Elongated body with scales, absence of limbs, pinnae and eyelids.

A key for identification of these animals can be prepared as follows.

1. External ears absent 2
   2. Wings present ....Bird
   2. Wings absent 3
   3. Gills present ....Fish
   3. Gills absent 4
   4. Limbs absent ....Snake
   4. Limbs present ....Frog
1. External ears present 5
   5. Wings present ....Bat
   5. Wings absent ....Cat

Another example of use of key for some vertebrates may be taken for cat, dog, cow, buffalo, goat, sheep, parrot, hen and duck.

1. Wings present 2
   2. Feet webbed ....Duck
      Feet unwebbed 3
   3. Upper beak movable .... Parrot
      Upper beak not movable ....Hen
1. Wings absent 4
   4. Skin covered with wool ....Sheep
      Skin not covered with wool 5
5. Teats four in number 6
   6. Horns coiled ....Buffalo
      Horns straight ....Cow
5. Teats two in number ....Goat
5. Teats several in number 7
   (canines present)
   7. Capable of climbing ....Cat
   7. Not capable of climbing ....Dog.

ADDITIONAL INFORMATION

- **Hornbill** (a bird) is the symbol of the Bombay Natural History Society.
- Kailash Sankhala wrote the widely acclaimed book **Tiger ! Tiger !**
- **The Silent Valley** is so called because it is silent during the night. It is in Kerala.
- Wild life Institute of India (WII), Dehradun.
- **"Appiko"** movement started in 1983 in Karnataka. 'Appiko' means the same as '**Chipko**'— hug.
- **Red Data Book.** This book contains a record of animals and plants which are known to be in danger. This book is maintained by IUCN.
- **The White Tiger.** All white tigers in the world are the progeny of a white male tiger which was captured in 1951 from the forest by the Maharaja of Rewa (M.P.) and reared as 'Mohan' at Govindgarh Palace.

- **Silviculture**— the cultivation of trees and management of forests or woodlands.
- **Ashoka** was the first ruler in recorded history to order the establishment of wildlife sanctuaries.
- **Keoladeo Ghana National Park, Bharatpur,** Rajasthan was once the duck-shooting ground of a king.
- **21st March**— World Forest Day.
- **22nd March**— World Water Day.
- **22nd April**— World Earth Day.
- **5th June**— World Environment Day.
- **3rd October**— World Animal Day
- **4th October**—World Habitat Day
- **3rd December**— World Conservation Day
- **BNHS**— Bombay Natural History Society
- **MAB**— Man and Biosphere Programme
- **WPSI**— Wildlife Preservation Society of India
- **NWAP**— National Wildlife Action Plan
- **IBWL**— Indian Board for Wildlife
- **IBP**— International Biological Programme\
- **IUCN**— The International Union for Conservation of Nature and Natural Resources
- **UNDP**— United Nations Development Programme
- **UNESCO**— United Nations Educational Scientific and Cultural Organisation
- **ZSI**— Zoological Survey of India.
- **BSI**— Botanical Survey of India.
- **Kaziranga National Park**, Assam *is a famous National Park for famous one-horned Rhinoceros of India.*
- **Gir National Park,** Gujarat is famous for the Asiatic lions.
- **Dachigam National Park,** J & K is world wide famous for Hangul stag.
- **Keibul Lamjao National Park,** Manipur is the *world's only floating National Park.*
- **Abohar Wildlife Sanctuary,** Punjab is a *privately owned agricultural area* belonging to 13 villages of Bishnoi community.
- The *first national park in the world*, the ***Yellowstone National Park*** was established on March Ist in 1872 in USA. The *first national park in India* was founded in 1935. It was named Hailey National Park/ Ramganga National Park which was later named as **Corbett National Park.**
- **Biosystematics.** Part of systematics connected with variations within a species and its general evolution. Also **new systematics.**

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Why are living organisms classified ?

   ✓ Organisms are classified because of the following reasons : (i) Easy identification (ii) Study of organisms of other places. (iii) Study of fossils (iv) Grouping helps in study of all types of organisms while it is impossible to study individually all of them. (v) It brings out similarities and dissimilarities. They help in knowing relationships among different groups. (vii) Evolution of various taxa can be known.

2. Why are classification systems changing every now and then ?

   ✓ Scientific study has been ever progressing due to continuous addition of newer tools and techniques. Earliest workers relied on only habitat and habits for classifying organisms. External morphology then became an important tool for classification. Anatomy and then embryology were used in

classification. Subsequently cellular structure, chromosomes, biochemical analysis and now DNA matching are being carried out to find out relationships and classify organisms. Therefore, classification systems have been changing, rather evolving with time. They have never been static.

3. What different criteria would you choose to classify people that you meet often ?

✓ (i) Family members (ii) Relatives (iii) Family friends (iv) School mates (v) Classmates (vi) Adults, seniors, same age and juniors (vii) Sex (viii) Height (ix) Playmates.

4. What do we learn from identification of individuals and populations ?

✓ **Individuals.** Each individual possesses a specific combination of traits not found in other members of the population.

Populations. (i) Each population is reproductively isolated. (ii) Members of a population interbreed amongst themselves. (iii) Members of a population resemble one another more than they resemble members of other populations. (iv) Karyotype is similar in all the individuals of a population. (v) There is a complete anatomical similarity amongst members of a population.

5. Given below is the scientific name of Mango. Identify the correctly written name *Mangifera Indica, Mangifera indica.*

✓ *Mangifera indica*

6. Define a taxon. Give some examples of taxa at different hierarchial levels.

✓ It is a unit in classification which may represent any level of grouping of organisms based on certain common characteristics like Maize (species), Roses (genus), grasses (family), conifers (order) dicots (class), seed plants (division), etc. The term was introduced for the first time by ICBN during 1956. Mayr (1964) has defined taxon to be a *taxonomic group of any rank that is sufficiently distinct to be worthy of being assigned to a definite category.* Simpson (1961) recognises taxon to be a group of real organisms recognised as a formal unit at any level of hierarchial classification.

7. Can you identify the correct sequence of taxonomical categories ?

(a) Species ⟶ Order ⟶ Phylum ⟶ Kingdom
(b) Genus ⟶ Species ⟶ Order ⟶ Kingdom
(c) Species ⟶ Genus ⟶ Order ⟶ Phylum

✓ Species ⟶ Genus ⟶ Order ⟶ Phylum

8. Try to collect all the currently accepted meaning for the word "species". Discuss with your teacher the meaning of species in cases of higher plants and animals on one hand and bacteria on the other hand.

✓ Species (i) It is a natural population or group of natural populations of individuals having similar morphology, anatomy, physiology and cytology. (ii) It is a basic unit of classification where individuals share a common genetic set up. (iii) Species is an assemblage of structurally similar individuals which interbreed freely amongst them but are reproductively isolated from members of other species.

Higher Plants and Animals. Higher plants and animals are sexually reproducing organisms. The criterion of reproductive isolation can be used for them. Therefore, third definition of the species given above is applicable to them.

Bacteria. The criterion of free interbreeding and reproductive isolation cannot be applied in their case as they do not reproduce sexually. Only the first definition of the species given above can be applied for them.

9. Define and understand the following terms : (i) Phylum (ii) Class (iii) Family (iv) Order (v) Genus.

✓ **(i) Phylum.** It is a higher grouping of organisms which is immediately below that of kingdom and above that of class. Phylum is a taxon consisting of one or more classes of organisms all of which possess some similar correlated characters, *e.g.*, jointed appendages in arthropoda.

(ii) Class. It is a taxonomic grouping of organisms higher than order and lower than phylum. Class is taxon that consists of one or more orders of organisms all of which possess some similar correlated characters, *e.g.*, three pairs of jointed legs in class insecta.

(iii) Family. Family is a grouping of organisms which is immediately below that of order and above that of genus. Family is a taxonomic category that consists of one or more genera of organisms all of which have some common correlated characters not found in genera of other orders, *e.g.*, family Asteraceae (Compositae) of flowering plants with capitulum inflorescence.

(iv) Order. It is a grouping of organisms higher than family and lower than class. Order is a taxonomic category having one or more families of organisms all of which possess some specific correlated characters not found in others, *e.g.*, order carnivora of mammals.

(v) Genus. It is a taxonomic category above the rank of species and below the rank of family. Genus is a grouping of organisms having one or more species all of which have common ancestry and share some common correlated characters, *e.g.*, *Panthera* of big cats.

10. How is a key helpful in the identification and classification of an organism?

✓ Key is a table of alternate characteristics arranged sequence wise which through selection and rejection is used in classification and identification of organisms.

Classification. Keys are available for knowing the phylum/division, class, order and family of the organisms in each system of classification. With their help every type of organism can be classified, whether it is known or unknown.

Identification. After knowing the family, identification key is used to know the genus and then the name of the species. If the organism is not already recorded, efforts are made first to check and recheck about its discovery and then given it a new name.

11. Illustrate the taxonomic hierarchy with suitable examples of a plant and an animal.

✓ Taxonomic hierarchy is the classification of organisms in a definite sequence of taxonomic categories in a descending order starting with kingdom and ending in species. Kindom → Phylum/ Division → Class → Order → Family → Genus → Species.

	Human	**Mango**
Kingdom	Animalia	Plantae
Phylum/Division	Chordata	Angiospermae
Class	Mammalia	Dicotyledonae
Order	Primata	Sapindales
Family	Homonidae	Anacardiaceae
Genus	*Homo*	*Mangifera*
Species	*sapiens*	*indica*

TEST QUESTIONS

One Mark Questions (Some With Answers)

1. Write the full form of ICBN.

   ✓ International Code of Botanical Nomenclature.

2. Write three codes of nomenclature.

   ✓ (i) International Code of Botanical Nomenclature (ICBN) (ii) International Code of Zoological Nomenclature (ICZN) and (iii) International Code of Bacteriological Nomenclature.

3. Why new names are derived from latin or are latinized ?

   ✓ This is because Latin language is dead and, therefore, it wil not change in form or spelling with the passage of time.

4. How many obligate categories constitute hierarchy of categories ?

   ✓ The hierarchy includes seven **obligate categories** - kingdom, division or phylum, class, order, family, genus and species.

5. What are polytypic genera?

   ✓ They are genera which have more than one species.

6. Name the two types of keys commonly used for indentification ?

   ✓ **Indented** (or yolked) and bracketed.

7. Why people give common vernacular names to organisms ?

   ✓ To identify the organisms.

8. How many plant and animal types do exist on earth ?

   ✓ There are 1.2 million types of animals and 0.5 million types of plants existing on earth.

9. What is organisation ?

   ✓ Organisation is the arrangement of smaller components of any structure, system or situation into larger ones and the larger ones into still larger ones in a hierarchy, where components of each level coordinate with one another towards a common goal.

10. Define life.

    ✓ Life is a unique, complex organisation of molecules expressing itself through chemical reactions which lead to growth, development, responsiveness, adaptation and reproduction.

11. Write the names of two important books brought out by Linnaeus.

12. Name the criteria used in modern taxonomic studies.
 ✓ Cytotaxonomy, Chemotaxonomy, Molecular Biology, Comparative studies of behaviour, morphology, anatomy and other aspects.

Two Mark Questions (With Sample Answers)

1. Why cannot the vernacular names be used by biologists ? Give any two reasons ?
 ✓ The vernacular names cannot be used by bioligists due to the following reasons.
 (i) All organisms do not occur in an area.
 (ii) All organisms occurring in a particular area cannot be given common names because some of them are microscopic or are unimportant to human affairs.
 (iii) Some common names have incorrect meaning, *e.g.*, Silver Fish, Jelly Fish, Cuttle Fish, Star Fish. They belong to different phyla and have no relationship with true fishes. Silver fish is not even aquatic.
2. Why have all organisms not yet been described and identified ?
 ✓ Many of the organisms occur in inaccessible areas like high mountains, steep valleys, tropical forests, coral reefs, arctic and antarctic regions. A few occasional visits do not help in surveying the whole biota.
3. Why do the wild animals rarely reproduce in zoo ?
 ✓ The area for free movement of wild animals is reduced which retard reproductive capacity of certain wild animals like rhino, tiger, bison, etc. This is one of the reasons why the wild animals in the zoo rarely reproduce.

Three Mark Questions (Short Answer Type)

1. How classical taxonomy is different from modern taxonomy ?
2. Why is the binomial system of nomenclature *acceptable* to biologists all over the world ?
3. What were the reasons for discarding the idea of fixity of species ?
4. What is the correct way of writing a scientific name ? Illustrate with example.
5. Define taxonomic hierarchy ? List the categories used in classification of organisms.
6. Which regions of the earth would show rich biological diversity ?
7. Define the terms : Identification, Nomenclature, Systematics, Taxonomy.
8. The common name of rice is simpler than its technical name *Oryza sativa* . What is the advantage of a technical name ?
9. Discuss the utility of systematics ?
10. How is a species of group revised ?
11. What are the traditionally regarded basic characteristics that unify all living organisms ?
12. What is death ? Mention the biological significance of death.
13. Define museum. How many kinds of museum are found ?
14. Name the first national park of the world. Write the name of the country in which it was established.
15. What is binomial nomenclature ? Give the method and rules of the same.
16. Why are common names not employed in scientific studies ?
17. On what basis the "New Systematics" differs from classical systematics? Mention about the various approaches which are adopted for classification under "New Systematics".
18. Explain the term species and hierarchical classification.
19. Describe the establishment of a zoological park.
20. How would you maintain a zoological park ?
21. How is systematics relevant to other branches of biology ?
22. Explain the utility of systematics.
23. What are the advantages of giving scientific names to the organisms ?
24. Binomial nomenclature is the most acceptable mode of naming organisms. Why ?
25. How do the biologists arrive at the universally acceptable names of plants and animals.
26. Botanical gardens are living herbaria ? Comment.

Five Mark Questions (Long Answer Type)

1. Develop a taxonomic key for the following : cat, dog, cow, buffalo, goat, sheep, parrot, hen, duck.
2. Distinguish between: (a) Systematics and taxonomy (b) Artificial and natural systems of classification (c) Species and taxon.

3. What are the three important characteristics of development ? Discuss the interrelationship between growth, development and reproduction in the maintenance of life.
4. What do you understand by herbarium ? Explain the various steps involved in preparing a herbarium specimen.
5. What is the role of keys in taxonomy ? Illustrate with example.
6. What is the role of zoological parks in wildlife conservation?
7. Illustrate the taxonomic hierarchy with suitable examples.

Multiple Choice Questions (With Answers)

(1) "Systema Naturae" is a book written by (a) Bentham and Hooker (b) John Ray (c) Lamarck (d) Linneaus. *(DPMT 2008)*

(2) Choose the correct sequence of taxonomic categories
(a) Class — Phylum — Order — Family — Genus — Species
(b) Division — Class — Order — Family — Genus — Species
(c) Division — Class — Family — Order — Genus — Species
(d) Phylum — Order — Class — Family — Genus — Species. *(KCET 2011)*

(3) Which is less general in characters as compared to genus (a) family (b) class (c) division (d) species. *(CBSE 2001; Odisha 2011)*

(4) Correct sequence in Linnaean hierarchy, is (a) species, genus, family, order, class (b) species, genus, phylum, family, class (c) class, family, species, genus, order (d) phylum, class, family, species, order. *(Karnataka 2001)*

(5) Animals and plants are best protected in (a) Zoos (b) Botanical gardens (c) Sanctuaries (d) National parks.

(6) Which one is not a category ? (a) Phylum (b) Species (c) Class (d) Glumaceae. *(BV 2002)*

(7) The term new systematics was given by Julian Huxley in (a) 1809 (b) 1840 (c) 1901 (d) 1940. *(BV 2002)*

(8) A true species consists of a population (a) sharing the same niche (b) interbreeding (c) feeding over the same food (d) reproductively isolated. *(CBSE 2002)*

(9) Who wrote "Species Plantarum" and provided a basis for classification of plants (a) Charles Darwin (b) Carolus Linnaeus (c) Robert Hooke (d) Leeuwenhoek. *(AIEEE 2004)*

(10) Botanical gardens provide (a) beautiful area for recreation (b) reservoir for tropical plants (c) *ex situ* conservation of germ plasm (d) natural habitat for wildlife. *(CBSE 2005)*

(11) Identify from the following, the category which has real existence (a) Kingdom (b) Phylum (c) Genus (d) Species. *(KCET 2006)*

(12) A living organism can be unexceptionally differentiated from a nonliving structure on the basis of (a) reproduction (b) growth and movement (c) interaction with environment and progressive evolution (d) responsiveness. *(CBSE 2007)*

(13) National Botanical Institute is located in (a) Kolkata (b) Chennai (c) Mumbai (d) Lucknow. *(DPMT 2007)*

(14) Number of species classified in "species Plantarum" is (a) 3800 (b) 4000 (c) 5900 (d) 6000. *(DPMT 2008)*

(15) Largest herbarium in India is located at (a) Indian Botanical Garden, Sibpur (b) Lloyd Botanical Garden, Darjeeling (c) National Botanical Garden, Lucknow (d) Forest Research Institute, Dehradum. *(Orissa 2009)*

(16) Related genera belong to the same (a) species (b) variety (c) family (d) breed. *(AFMC 2009)*

(17) Scientific study of diversity of organisms and their evolutionary relationships is called (a) morphology (b) anatomy (c) taxonomy (d) systematics. *(J&K CET 2011)*

(18) The term taxonomy is introduced by (a) De Candolle (b) Benthum and Hooker (c) Linnaeus (d) Huxley. *(J&K CET 2011)*

(19) The framework system of classification in which various taxonomic categories are arranged in order of logical sequence is called (a) systematics (b) classification (c) hierarchy (d) taxon. *(J&K CET 2011)*

(20) The basic unit of classification is (a) species (b) genus (c) family (d) phylum. *(J&K CET 2011)*

(21) Carolus Linnaeus is associated with (a) inheritance of acquired characters (b) binomial nomenclature (c) law of independent assortment (d) law of limiting factors. *(AMU 2011)*

(22) In the nature, the biologically cohesive unit amongst the taxa is (a) genus (b) order (c) phylum (d) species. *(HP PMT 2012)*

(23) Taxon is the unit of (a) Species (b) Genus (c) Order (d) Taxonomy. *(JK CET 2013)*

(24) Which is not correct (a) A museum has collection of photographs of plants and animals. (b) Botanical gardens have collection of living plants for reference (c) Herbarium houses dried, pressed and preserved plant specimens (d) Key is taxonomic aid for identification of specimens. *(NEET 2013)*

(25) Which one shows the correct hierarchical arrangement (a) Kingdom ← Division ← Class ← Order ← Family ← Species ← Genus (b) Kingdom ← Division ← Order ← Class ← Family ← Genus ← Species (c) Kingdom → Division → Order → Class → Family → Genus → Species (d) Kingdom → Division → Class → Order → Family → Genus → Species (e) Kingdom → Division → Family → Order → Class → Genus → Species. *(Kerala 2014)*

(26) The objective of 'Ramsar Convention' was (a) forest conservation (b) wildlife conservation (c) wetland conservation (d) biodiversity conservation. *(WB-JEE 2014)*

(27) Who gave the nomenclature according to which humans are called *Homo sapiens*
(a) Darwin (b) Mendel (c) Aristotle (d) Linnaeus. *(Bihar 2015)*

(28) Nomenclature is governed by certain universal rules. Which one of the following is contrary to the rules of nomenclature (a) when written by hand, the names are to be underlined (b) biological names can be written in any language (c) the first word in a biological name represents the genus name and the second is a specific epithet (d) the names are written in Latin and are italicised. *(NEET 2016)*

(29) The label of a herbarium sheet does not carry information on (a) height of the plant (b) date of collection (c) name of collector (d) local name. *(NEET 2016)*

(30) Which of the following is the correct scientific name of wheat derived by binomial nomenclature
(a) *Triticum vulgare* (b) *Triticum aestivum* (c) *Oryza* sativa (d) Zea mays. *(AIIMS 2016)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as
(a) If both A and R are true and R is the correct explanation of A
(b) If both A and R are true and R is not correct explanation of A
(c) If A is true but R is false. (d) If both A and R are false.

(1) **Assertion :** Systematics is branch of biology that deals with classification of organisms.
Reason : Aim of classification is to group the organisms in orderly manner.
A B C D

(2) **Assertion :** Scientific name *Malus malus* is illegitimate.
Reason : It is tautonym. *(EAM CET 2005)*
A B C D

(3) **Assertion :** Consciousness is considered as defining property of living organisms.
Reason : All organisms from prokaryotes to most complex eukaryotes can sense and respond to environmental stimuli. *(AIIMS 2016)*
A B C D

ANSWERS

Miscellaneous Questions

1. (a) Taxon (b) Indica (c) Chordata
2. (a) Phylum (b) Phylum (c) Order (d) Phylum
3. (a) Family (b) Species (c) Order

Multiple Choice Questions

(1) —d (2) —b (3) —d (4) —a (5) —d (6) —d (7) —d (8) —d (9) —b (10) —c
(11) —a (12) —a (13) —d (14) —c (15) —a (16) —c (17) —d (18) —c (19) —c (20) —a
(21) —b (22) —d (23) —d (24) —a (25) —d (26) —d (27) —d (28) —d (29) —a (30) —b

Assertion and Reason Type Questions

(1) —B (2) —A (3) —A.

2 BIOLOGICAL CLASSIFICATION

Biological classification is the scientific procedure of arranging organisms into groups and subgroups on the basis of their similarities and dissimilarities and placing the groups in a hierarchy of categories.

NEED FOR CLASSIFICATION

A proper system of classification is a must because of the following reasons.

(1) It is not possible to study every organism. The study of one or two organisms of a group gives sufficient information about the essential features of the group.

(2) Without any system of classification organisms cannot be identified.

(3) All types of organisms do not occur in one locality.

(4) The organisms of the past cannot be studied without a proper system of classification.

(5) Classification helps in knowing the relationships amongst different groups of organisms.

(6) On the basis of relationship and simplicity or complexity found in the members of various taxa, evolutionary tendencies can be known.

Objectives of Classification

(i) To identify and describe all the possible types of species.

(ii) To arrange the species in various categories on the basis of their similarities and dissimilarities.

(iii) To evolve a natural or phylogenetic system which should indicate origin and evolution of the species.

(iv) Helping in easy identification of organisms.

Types. There are three main types of classification — artificial, natural and phylogenetic.*

Artificial System of Classification

It is a system of classification which uses one or two morphological characters for grouping of organisms. Some artificial systems have used habit and habitat for this purpose. Aristotle (c 350 BC) divided animals into two categories, **enaima** (with red blood) and **anaima** (without red blood). Aristotle also classified animals on the basis of their habitat—aquatic (*e.g.*, fish, whale), terrestrial (*e.g.*, reptiles, cattle) and aerial (*e.g.*, birds, bat). Pliny the Elder (23-79 A.D.) used artificial system of classification for both plants and animals dividing them into land, air and water. Pliny distinguished animals into **flight** and **nonflight** ones. Flight animals included bats, birds and insects. Linnaeus also put forward an artificial system of plant classification on the basis of numerical strength of sex organs into 24 classes

*Given in NCERT under plant kingdom.

like monandria, diandria, polyandria, didynamia, monoecia, cryptogamia, etc. Artificial system is easier to practise in the field. But it has several drawbacks like :

(1) It does not study homology but is mostly based on convergence.

(2) The system employs one or two morphological and ecological traits which have no bearing on the actual status of taxa.

(3) The characters picked up for artificial system of classification, show progressive, retrogressive or parallel evolution. Therefore, they do not reflect any natural relationship.

(4) Organisms do not show a clear cut evolutionary line. In some characters they may be more advanced than their relatives while in others they may be primitive.

(5) Organisms of different affinities get arranged in the same group like birds, bats and insects in flight animals or cacti, euphorbias and halophytes among succulent plants. Linnaeus' monandria includes both dicots and monocots while his didynamia has both labiatae as well as gymnosperms.

(6) Some characters used in artificial system of classification get changed with change in environment like biennial and annual habit of radish, large and small leaves.

(7) The system does not give any idea about natural relationships amongst different taxa.

Natural System of Classification

It is a system of classification which takes into consideration comparable study of a number of characters so as to bring out natural similarities and dissimilarities and hence natural relationships among the organisms. The system employs those characters which are relatively constant. They include morphological characters, anatomical characters, cytological characters, physiology, ontogeny or development, reproduction, cytochemistry and biochemistry, experimental taxonomy, etc. The characteristics are helpful in bringing out maximum number of similarities in a group and comparable differences with other groups of organisms. For example, mammals are characterised by the presence of mammae, hair, vivipary, 4-chambered heart, denucleated erythrocytes and warm blooded nature. Birds possess wings, feathers, pneumatic bones, ovipary, 4-chambered heart, nucleated erythrocytes and warm-blooded nature. Similarly, fishes do not possess limbs but fins. Their body is covered with scales. Respiration is through gills. Heart is two-chambered. They are cold-blooded.

In natural system of classification, homology is brought out through the study of internal and external characters. **Homology** is the relationship of comparable structures having been derived from a common form. For example, the fore arm of different land vertebrates has the same pentadactyl constitution. It is externally much different in different organisms to perform different functions like grasping in human beings, running in horse, swimming in whale, flight in bird or a bat. Homology shows how each organ or structure has evolved in different groups to suit different functions. Homology is studied in case of biochemicals as well. **Molecular homology** is the finding of relationship of comparable molecules like DNA, RNA and proteins by studying their similarities and dissimilarities. Even certain biochemicals occur in specific groups, *e.g.*, betacyanin is found in beet root and related plants. The branch of biology that utilizes the study of chemicals in classification is called chemotaxonomy. Chromosomes or karyotypes are also important for knowing natural relationships.

In the ninteenth century many comparative studies were not available. Scientists relied more upon morphological and anatomical characters than other characters. A natural system for classification of seed plants was proposed by Bentham and Hooker (1862–1883) in their three-volumes treatise '*Genera Plantarum*'. These days a natural system of classification

not only brings out natural relationships but also studies the evolutionary tendencies and phylogeny with the help of all the available data including fossils.

Natural system of classification is certainly better than any artificial system of classification because

(a) There is stress on actual study of each and every organism.
(b) There is stress on comparative study.
(c) It brings about affinities on the basis of a number of characters.
(d) It brings out natural relationships amongst organisms.
(e) It places only related organisms in a group.
(f) The system prevents coming together of unrelated organisms.
(g) The system indicates phylogenetic relationships and the origin of different taxa.

Differences between artificial and natural systems of classification

Artificial System	*Natural System*
1. The system is highly useful in the field for quick identification of organisms.	1. A natural system often employs artificial keys for quicker identification in the field because the system as such is difficult to operate in the field.
2. Artificial system often utilizes one or two morphological traits.	2. The system employs several morphological characters for grouping of organisms.
3. An artificial system may use habit and habitat as criteria for grouping.	3. A natural system never uses habit and habitat as criteria for classification.
4. The system does not employ characters from anatomy, cytology, cytochemistry, biochemistry, genetics, ontogeny, etc., for grouping of organisms.	4. The system employs all these informations.
5. Homology is never studied.	5. It studies homology in all characters including morphology, anatomy, cytotaxonomy, molecular systematics, etc.
6. The system gives no information about natural relationships or phylogeny.	6. This system gives information about both natural relationships and phylogeny.
7. It often results in placing of unrelated organisms in a group.	7. There is little chance of placing of unrelated organisms in a group.
8. Related organisms often get separated into different groups.	8. Related organisms are placed in the same group.

Phylogenetic System of Classification

Classification based on evolutionary relationships of organisms is called **phylogenetic system of classification**. It is based on the evolutionary concept from Darwin's book— *On the Origin of species by Means of Natural Selection : The Preservation of Favoured Races in the Struggle for Life* (1859). It reflects the true relationships among the organisms. First phylogenetic system was proposed by Engler and Prantl (1887-99). In their treatise '*Die Naturlichen Pflanzen Familien*' Engler and Prantl arranged flowering plants according to increasing complexity of their floral morphology. They considered absence of perianth or presence of one whorl of perianth, unisexual flowers and anemophily primitive to flowers with two whorls of perianth, bisexual flowers and entomophily respectively. **Monocots were considered primitive to dicots**. However, achlamydeous and monochlamydeous conditions

can develop through retrogressive evolution from dichlamydeous condition. Their treatment of Asteraceae amongst dicots and Orchidaceae amongst monocots to be most advanced is correct. The major drawback of the system is that it considered evolution of angiosperms from a single stock (monophyletic origin). Improved phylogenetic systems were later proposed by Hutchinson (1959) and Takhtajan (1966). However, a phylogenetic system is not static but highly **dynamic**. Its major source is fossil record. The same, however, is never complete due to difficulty in formation, exposure, discovery and study of fossils. As newer fossils are discovered, newer relationships are observed and consequently, phylogenetic system is changed and updated. Botanists and zoologists, however, differ in their concept of phylogenetic system. **Zoologists believe that since similarity in structure represents close evolutionary relationship, their natural classification represents evolutionary and phylogenetic classification.** Botanists do not believe in the same. They have noticed innumerable differences in the evolutionary trends of plants. A single genus of higher plants shows several advanced and primitive characters. It may resemble two or more families in its different characters. This is true because evolution does not mean unidirectional development in all the characters. Variations appear in different degrees in different traits. The selection process depends upon environment and competition. As a result a phylogenetic system can at best be partly evolutionary and partly numerical in its nature.

Differences between Natural and Phylogenetic Systems

Natural System	*Phylogenetic System*
1. The system is based on resemblances and differences amongst organisms.	1. It is based on possible evolution of different traits.
2. There is little role of fossils.	2. Fossils play vital role in elucidation of evolutionary relationships.
3. It is more practicable.	3. It is less practicable because organisms have both primitive and advanced characters and fossil record is not available in every case.

Phenetic Classification or Taximetrics (Gk. *phainein*– to appear)

It is a system of phylogenetic classification which is based on affinities, similarities and dissimilarities of characteristics present in the present day organisms without searching for the evolution and diversification of these traits in their fossil ancestors. The classification obtains supporting evidences from four major branches of taxonomy— cytotaxonomy, chemotaxonomy, numerical taxonomy and cladistic taxonomy.

1. **Cytotaxonomy.** It is classification based on information provided by comparative cytological studies, number of chromosomes, structure and meiotic behaviour of chromosomes. It is known that fewer and larger chromosomes have been formed in many cases by fusion of smaller chromosomes. Herbaceous plants have larger chromosomes than those of woody plants. Naturally, herbaceous plants are more advanced than the woody plants. In many genera the same basic chromosome number has been found in different species, *e.g.*, 12 in *Solanum* species and 9 in *Chrysanthemum* species. Human beings have 46 chromosomes while apes have 48. A reduction in number of chromosomes have been achieved through whole arm translocation between two acrocentric chromosomes. Apparently, humans have evolved from ape-like ancestors. Pairing of chromosomes during meiosis helps to bring out relationships between species.

2. **Chemotaxonomy** (Biochemical Systematics). The system of classification is based on characteristics of various chemical constituents of organisms like amino acids, proteins, DNA sequences, alkaloids, crystals, betacyanins, etc. Chemical constituents of plants are generally specific and stable. They do not change easily. Ancient medical men based their identification of plants on fragrance, taste and other chemical characteristics. Crystals of calcium oxalate like raphides are restricted to 35 families. Similarly, certain alkaloids are restricted to a few related families, *e.g.*, benzylisoquinoline alkaloid in *Papaveraceae*, Berberidaceae and Ranunculaceae.

Differences between Cytotaxonomy and Chemotaxonomy

Cytotaxonomy	*Chemotaxonomy*
1. It is taxonomy based on comparative cytological studies.	1. It is taxonomy based on characteristics of chemical constituents.
2. Presence of similar banding pattern of chromosomes indicates close similarity.	2. Presence of certain specific chemicals in certain groups of organisms shows close relationships.
3. Lineage can be traced with the help of chromosome studies, *e.g.*, humans from apes.	3. DNA analysis and protein tests are useful in knowing relationships.

3. **Numerical Taxonomy.** It evaluates resemblances and differences or primitiveness and advancement through statistical methods based on a large number of characters obtained from all disciplines of biology. This is followed by assigning them number and codes of computer like plus (+), minus (–), θ (data not available), followed by computer analysis. It establishes the numerical degree of relationship among individuals. The relationship or affinity values are then used to erect taxonomic categories. However, its effectiveness depends upon the judgement of the biosystematist in selecting characters and current knowledge about them.

4. **Cladistic Taxonomy** (Gk. *clados*– sprout). It searches similarity due to common **phylogeny** or origin from a common ancestor. These are two types of characters, ancestral and derived. **Ancestral characters** are traits of basic body design which would be present in an entire group. **Derived characters** are those traits whose structures and functions differ from those of ancestral characters. They appear during evolution and cause the formation of new subgroups. One or more derived characters would be shared by an entire subgroup. In cladistic taxonomy (cladistics) each evolutionary step produces a branching. All the members of a branch would possess the derived character. It will be absent below the branch point. Arranging organisms on the basis of their shared similar or derived characters, that differ from ancestral characters, will produce a phylogenetic tree called **cladogram**.

Depending upon the type of system of classification, organisms are classified into two kingdoms or three kingdoms, four kingdoms, five kingdoms and now into six kingdoms.

1. Two Kingdom Classification (Before 1969)

In the past all the organisms had been divided into two groups, plants and animals, mainly on the basis of presence or absence of cell wall. This was also done by Linnaeus (the father of taxonomy). He founded two kingdoms— **Kingdom Plantae** (regnum vegetable) and **Kingdom Animalia** (regnum animale).

The members of kingdom plantae are plants. They are distinguished by (i) presence of cell wall, (ii) occurrence of inorganic crystals in the cells, (iii) presence of central vacuole in the cell, (iv) absorption of inorganic nutrients from outside, (v) well defined growing points with unlimited growth, (vi) absence of excretory organs, sense organs and nervous

system, (vii) ability to manufacture food due to presence of chlorophyll — holophytic or autotrophic nutrition, (viii) reserve food as starch, (ix) occurrence of branches and less definite shape, (x) absence of locomotion, (xi) absence of muscular tissue, (xii) presence of external organs and (xiii) slow response to external stimuli.

Members of kingdom animalia possess the opposite characters as (i) absence of cell wall, (ii) inorganic crystals are not present in their cells, (iii) absence of central vacuole in the cell, (iv) ingestive (holozoic) type of nutrition, (v) well defined growing points absent, growth limited, (vi) presence of excretory organs, sense organs and nervous system, (vii) inability to manufacture food due to absence of chlorophyll, (vii) reserve food as glycogen, (ix) absence of branches and having definite shape, (x) presence of locomotion, (xi) muscular tissue present, (xii) organs internal and (xiii) quick response to external stimuli.

Several objections have been raised against this two kingdom classification. They are :

(i) First formed organisms were neither plants nor animals.

(ii) Fungi differ in the structure, physiology and reproductive details from plants.

(iii) At the lower level of organisation there are several instances where the distinction of plant and animal disappears. For example, *Euglena* has both holophytic and saprobic nutrition (mixotrophic nutrition). Its relatives have both holophytic and holozoic nutrition. Sponges are branched, fixed and irregular in outline just like plants. Unicellular algae like *Chlamydomonas* are motile, possess regular shape, definite growth and photosensitive organelles.

(iv) Slime Moulds, a group of fungi, are wall-less in the vegetative phase when nutrition is holozoic. They develop cell walls in the reproductive phase. Slime moulds can neither be placed in fungi, nor plants. This group is popularly called an **animal group** which is studied by mycologists.

(v) Lichens constitute a peculiar group of dual organisms which are formed by an association between an alga and a fungus. They have no plant character, neither any animal character.

(vi) Viruses have a volume of 10^{-6} to 10^{-3} μm^3. Procaryotes have a volume range of 0.2 to 10 cubic μm^3 while the average eucaryotic cell has volume between 1000–10000 μm^3. All of them cannot occur in a single kingdom.

(vii) Prokaryotes have a single compartment or **single envelope organisation** where plasma membrane forms the only covering that encloses the whole cell. Genetic material is naked as organised nucleus is absent. Sexual reproduction, meiosis and spindle apparatus are absent. Viruses have no protoplasm and metabolic machinery of their own. On the other hand, eucaryotes have **two envelope** or two compartment **organisation.** Plasma membrane forms the outer chamber while, nuclear envelope creates an inner chamber. Sexual reproduction, meiosis and spindle apparatus are absent. Therefore, the three must be separated from one another.

(viii) Groups of unicellular algae (euglenoids, diatoms and dinoflagellates) and protozoa show sufficient degree of resemblance.

2. Three Kingdom Classification

Haeckel (1866) *separated unicellular animals, algae and fungi from other organisms on the basis of lack of tissue differentiation. The new group was called* **kingdom protista**. Later on fungi and multicellular algae were taken out from the group so that kingdom protista came to have only unicellular organisms divided into three kingdoms— Plantae, Protista and Animalia.

3. Four Kingdom Classification

With the advent of electron microscope, it became clear that bacteria and related organisms have a different nuclear structure as compared to others. They are procaryotes in

contrast to others which have a true nucleus and are called eucaryotes. **Copeland** (1956) created a separate kingdom of **monera** (= Mychota) for them. This divided the living world into four kingdoms— Monera, Protista, Plantae and Animalia. In this system, fungi continued to remain with the plantae.

4. Five Kingdom Classification (From 1969 to 1990)

In order to develop phylogenetic classification, **R.H. Whittaker** (1969), an American taxonomist, divided all the organisms into five kingdoms. As the viruses are on the border line of living and nonliving, they have been left out. Whittaker has used **five criteria** for delimiting the **different** kingdoms. (i) Complexity of cell structure, prokaryotic and eucaryotic (ii) Complexity of body structure or structural organisation, unicellular and multicellular. (iii) Mode of nutrition which is divergent in multicellular kingdoms— photoautotrophy in plantae, absorptive heterotrophy in fungi and ingestive heterotrophy in animalia. Photoautotrophic nutrition is also called **holophytic nutrition** while ingestive heterotrophy is known as **holozoic nutrition**. Absorptive heterotrophy is **saprobiotic** (= saprophytic) **nutrition**. Mode of nutrition also determines the ecological life style like producers (plantae), decomposers (fungi) and consumers (animalia). (iv) Presence or absence of sexual reproduction, mode of sexual reproduction. (v) Phylogenetic relationships.

Whittaker's five kingdoms are Monera, Protista, Plantae, Fungi and Animalia.

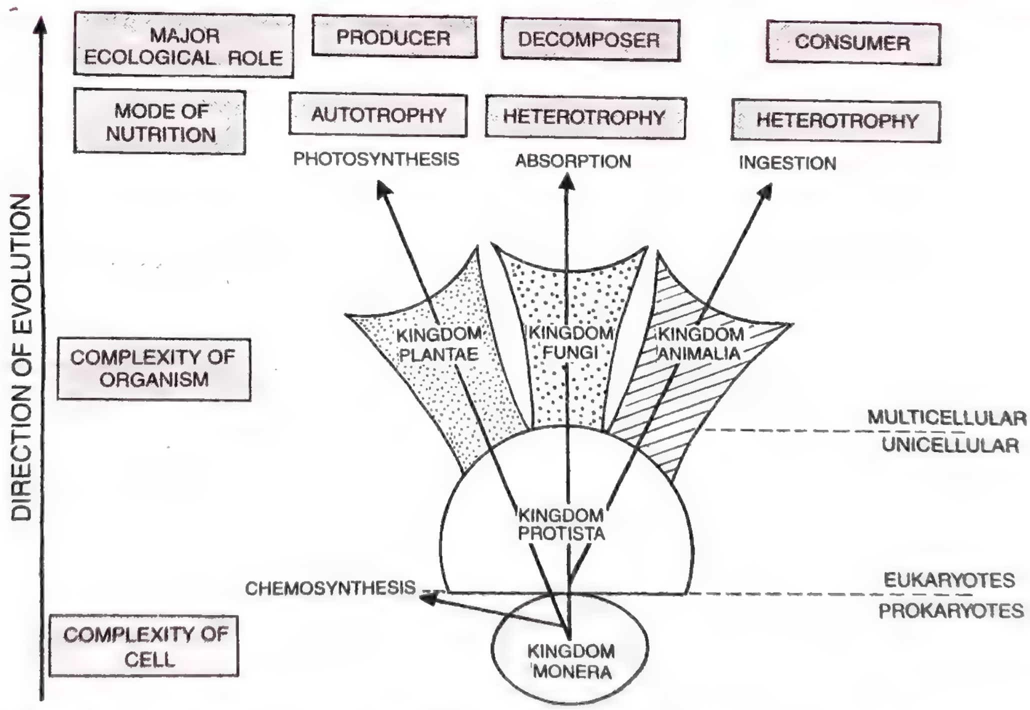


Fig. 2.1. Five kingdoms of Whittaker (1969) based on cell structure, structural complexity, nutrition and ecological role.

Monera— Kingdom of Procaryotes

The kingdom includes all procaryotes— mycoplasma, bacteria, actinomycetes and cyanobacteria or blue green alge. Alongwith fungi, they are decomposers and mineralisers of the biosphere.

(i) Monerans are basically unicellular (*monos*-single) procaryotes and contain the most primitive of living forms. (ii) They are varied in their nutrition— saprobic, parasitic, chemoautotrophic, photoautotrophic and symbiotic. The photoautotrophs include both aerobes and

anaerobes. (iii) The cells are microscopic (0.1 to a few microns in length). (iv) Cell wall is generally present. It contains peptidoglycan and polysaccharides other than cellulose. (v) Cells have **one envelope type of organisation,** *i.e.*, the whole protoplast is covered by plasma membrane but internal compartmentalisation is absent. (vi) Genetic material is not organised into a nucleus. (vii) DNA is naked, *i.e.*, it is not associated with histone proteins. DNA lies coiled inside the cytoplasm. The coiled mass is known as nucleoid. It is equivalent to a single chromosome. (viii) All membrane bound cell organelles are absent, *e.g.*, mitochondria, lysosomes, spherosomes, golgi bodies, plastids, etc. (ix) The flagella, if present, are single stranded instead of being 11 stranded in eucaryotes. They are formed of protein called flagellin. (x) Mitotic spindle is absent. (xi) Gametes are absent. Gene recombination has been discovered in certain cases. Otherwise reproduction is by asexual methods. (xii) Some of the monerans have the ability to convert dinitrogen into ammonia state.

Protista— Kingdom of Unicellular Eucaryotes

It is kingdom of unicellular eukaryotic organisms. **Kingdom Protista has brought together *Chlamydomonas, Chlorella* (earlier placed in Algae within Plants and both having cell walls)** with *Paramoecium* and *Amoeba* (which were earlier placed in the animal kingdom which lack cell wall.

Kingdom protista includes flagellates (euglenophyceae), diatoms, dinoflagellates, slime moulds, sarcodines, ciliates, sporozoans, etc. The important characteristics are: (i) It includes all unicellular and colonial eucaryotes. (ii) Mostly they are aquatic organisms forming plankton. (iii) They have diverse modes of nutrition— photosynthetic, saprobic, parasitic, ingestive, or holozoic etc. (iv) The photosynthetic plankton are called **phytoplankton**. They usually possess cell wall and constitute an important group of producers. The non-photosynthetic, wall-less and holozoic plankton are called **zooplankton**. Holozoic nutrition involves ingestion of particulate food. The protistans having holozoic nutrition are collectively called protozoa, though they have been excluded from kingdom animalia. (v) There is a group of Euglena-like organisms which have a dual mode of nutrition, holophytic or photosynthetic in light and holozoic in absence of light or presence of abundant organic matter. Slime moulds are a group of protista which are intermediate between wall-less and walled organisms. They are devoid of a wall in vegetative phase. In the vegetative phase, the nutrition is of ingestive type. In the reproductive phase, the slime moulds come to have cell walls. (vi) The cellular organisation is of two envelope type, *i.e.*, besides plasma membrane, internal membranes occur around certain organelles. (vii) Genetic material is organised in the form of nucleus. DNA is associated with histone proteins. (viii) The aerobic forms possess mitochondria. Endoplasmic reticulum, golgi bodies, lysosomes and centrioles occur. (ix) Flagella, if present, are 11 stranded with 9 + 2 organisation of microtubules that are composed of a protein named **tubulin**. (x) Both sexual and asexual modes of reproduction are present. However, an embryo stage is absent. (xi) Tissue system is, absent.

Kingdom protista does not seem to be a natural group due to (i) Dinoflagellates are mesokaryotic and not eucaryotic. (ii) A distinction of unicellular protistan algae and green

algae included in volvocales is not valid. (iii) Slime moulds are quite distinct from rest of the protists. (iv) There are several evolutionary lines in protista. (v) Protists of this kingdom have diverse modes of form, structure and life.

Differences between Monera and Protista

Monera	Protista
1. The kingdom consists of prokaryotic organisms.	1. The kingdom contains eukaryotic organisms.
2. The organisms are unicellular, colonial, mycelial and filamentous.	2. The protists are unicellular or colonial.
3. Cell size is smaller (0.1-5 μm).	3. Cell size is larger (10-100 μm).
4. The cell wall contains peptidoglycans.	4. The cell wall if present contains cellulose.
5. Flagella, if present are unistranded.	5. Flagella if present are 11-stranded.
6. There is a single envelope system.	6. There is a double envelope system.
7. Ribosomes are 70S in nature.	7. Cytoplasmic ribosomes are 80S while organelle ribosomes are 70S.
8. Membrane bound cell organelles are absent.	8. Membrane bound organelles are present.
9. An organized nucleus is absent.	9. An organized nucleus is present.
10. Genetic material is a single double helix molecule of DNA.	10. Genetic material consists of two or more DNA molecules.
11. Sap vacuoles are absent.	11. Sap vacuoles occur.
12. Cell division occurs by amitosis as a mitotic spindle is absent.	12. Cell division occurs by mitosis due to presence of spindle.
13. Sexual reproduction is absent as meiosis does not occur.	13. Sexual reproduction is generally present as meiosis can occur.

Fungi— Kingdom of Multicellular Decomposers

The kingdom includes moulds, mildews, yeasts, rust causing fungi, pencillium, morels, mushrooms, puff balls, bracket fungi, etc., *i.e.*, all the fungi of the two kingdom classification except slime moulds. (i) It contains achlorophyllous, spore producing, multicellular or multinucleate eukaryotic organisms. Basically unicellular yeasts are also included amongst fungi because their sexual reproduction is similar to that of some fungi. (ii) The organisms are heterotrophic with absorptive type of nutrition. It is either saprobic or parasitic. Symbiotic association occurs with some algae and higher plants, *e.g.*, lichens, mycorrhiza. The saprobic fungi excrete hydrolytic or digestive enzymes in the external medium for digesting complex organic compounds. The parasitic fungi absorb nourishment directly from another living organism called host. (iii) The body of fungus is filamentous and is called **mycelium**. The filaments are known as **hyphae**. (iv) Hyphae are either multicellular or multinucleate. Nuclei are very small and show intranuclear spindle. (v) The wall contains chitin and noncellulosic polysaccharides. Cellulose also occurs in a few cases. (vi) The cellular organisation is two envelope type. (vii) In most cases, golgi bodies are unicisternal. (viii) Reproduction is both asexual and sexual. (ix) Vegetative body or mycelium is not clear externally in most of the cases due to its subterranean nature. Reproductive bodies, are, however, apparent as in mushrooms, toadstools, puff balls, bracket fungi. (x) Tissue differentiation is absent. (xi) Food reserve is glycogen and fat.

The kingdom is important in nutrient cycling because along with some protistans and monerans, fungi are decomposers and mineralisers of the biosphere.

Plantae — Kingdom of Multicellular Producers or Metaphyta

The kingdom contains all photosynthetic eucaryotic multicellular plants and their non-photosynthetic relatives. At the lower level it contains multicellular algae— green, brown and red algae. Other groups included in the kingdom plantae are bryophytes, pteridophytes and spermatophytes. Important characters of this kingdom are as follows : (i) Organisms are multicellular. (ii) They are eucaryotic. (iii) Body form is less regular. (iv) Growth is usually indefinite. (vi) Organs are commonly external. (vii) Irritability is poor. (viii) Mode of nutrition is autotrophic. (ix) The photosynthetic regions contain plastids in their cells. Due to photosynthetic activity, plants are called **producers**. (x) Most of the plants are restricted to land, sea-shores and fresh water reserviors. (xi) The plants are usually fixed or free floating. Active locomotion is generally absent. (xii) Structural differentiation into tissues is found except for certain algae. (xiii) Food reserve is usually starch and fat. (xiv) Some of the plants are heterotrophic. They are mostly parasitic. A few are saprobes. A small group of autotrophic plants catch small animals and insects for obtaining extra nitrogen. They are called **carnivorous** or **insectivorous plants**. (xv) Reproduction is both asexual and sexual. Accessory spores are present in lower plants. An embryo stage is absent in the algal group but is present in others.

Animalia — Kingdom of Multicellular Consumers or Metazoa

Members of this kingdom are also known as **metazoa** or multicellular animals. The kingdom has **maximum number** and most diverse types of organisms. It includes all the animals of the two kingdom classification except Protozoa. Groups included are sponges, coelenterates, worms, molluscs, arthropods, star fishes and vertebrates like fishes, amphibians, reptiles, birds and mammals. Insects, a group of arthropods, outnumber all other organisms in variety and number. The important characteristics of animalia are : (i) Organisms are multicellular eucaryotes. (ii) Body form is regular. (iii) Organs are internal. (iv) Growth is definite. Well defined growing points are absent. (v) Cellular, tissue and organ-system levels of organisation occurs in different groups. (vi) Response to stimuli is quick. (vii) A cell does not possess central vacuole. Instead small vacuoles may occur. (viii) Centrioles occur in the cells. (ix) A cell wall is absent. (x) Plastids and photosynthetic pigments are absent. (xi) The organisms have holozoic or ingestive type of nutrition. A few animals are, however, parasitic. They live on or inside the bodies of other eucaryotes. (xii) Animals are motile or mobile as they have to search for their food. Sponges and corals are an exception. (xiii) The organisms possess muscle cells for their mobility and nerve cells for conduction of impulses. They are, however, absent in sponges. (xiv) Reproduction is mostly sexual. Regeneration of whole organism and formation of spores are found in lower animals. (xv) Embryo stage is present. (xvi) Ecologically animals are consumers. These consumers constitute links in the food chains and food webs.

Advantages of Five Kingdom Classification

1. Separation of prokaryotes in a separate kingdom of Monera is a wise step because procaryotes differ from all other organisms in their genetic, cellular, reproductive and physiological organisation.

2. Many transitional or intermediate forms are present in the unicellular eucaryotes which had been included both amongst plants and animals. Separation of unicellular eucaryotes into kingdom protista has removed this anomaly.

3. Fungi have never been related to plants. They have their own biochemical, physiological and structural organisation. Separation of fungi into a separate kingdom was long overdue.

4. The five kingdom classification is based on levels of organisation and nutrition which evolved very early and became established in later groups that are existing today.

5. In this classification, animal and plant kingdoms are more homogeneous than they are in two-kingdom classification.

6. It has tried to bring out phylogenetic relationships even amongst the primitive forms.

Table 2.1. Characteristics of Five Kingdom

S.No.	Characters	Monera	Protista	Fungi	Plantae	Animalia
1.	Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
2.	Cell Wall	Non-cellulosic (Polysaccharide + Amino Acid)	Present in some (Various types)	Present (Non cellulosic)	Present (Cellulose)	Absent
3.	Chloroplast	Absent	Present in some	Absent	present	Absent
4.	Mitochondria	Absent	Present	Present	Present	Present
5.	Nuclear Membrane	Absent	Present	Present	Present	Present
6.	Tissue or Multicellularity	Absent	Absent	Present but limited	Present in all forms	Present in all forms
7.	Motility	Bacterial flagella, gliding or non-motile	Cilia, Flagella amoeboid or contractile fibrils	Cilia, Flagella in some, none in most of the forms	Cilia and Flagella in lower forms, absent in most of the forms	Cilia and flagella, contractile fibrils
8.	Mode of nutrition	Autotrophic-chemosynthetic and photo-synthetic, heterotrophic (saprophytic and parasitic)	Phosynthesis and heterotrophic	Heteroprophic, Saprophytic and parasitic absorptive	Autotrophic by photosynthesis	Heterotrophic by ingestion
9.	Reproduction/-means of genetic recombination	Conjugation, Transduction, Transformation or none	Syngamy and meiosis, conjugation or none	Fertilization and meiosis, dikaryosis or none	Fertilization and meiosis	Fertilization and meiosis
10.	Nervous system	Absent	Primitive for conducting stimuli	Absent	Absent	Present, often complex

Drawbacks of Five Kingdom Classification

1. In real terms the phylogenetic system cannot be established till all the distinct evolutionary tendencies are separated. This is not possible at the lower level. For example,

certain green algae are known to obtain hydrogen from sources other than water like photosynthetic bacteria. Similarly, *Euglena* can be photosynthetic as well as saprotrophic. Its relatives can have absorptive as well as ingestive type of heterotrophic nutrition.

2. A distinction between unicellular and multicellular organisms is not possible in case of algae. It is because of this that unicellular green algae have not been included in kingdom Protista by Whittaker.

3. Each group has so many diversities that it is difficult to keep them together. For example, monera and protista contain both walled and wall-less organisms, photosynthetic and nonphotosynthetic organisms, unicellular and filamentous or mycelial organisms.

4. Viruses have not been included in this system of classification.

5. Archaebacteria differ from other bacteria in structure, composition and physiology.

6. Mycoplasmas are quite different from bacteria where they have been placed alongwith prokaryotes.

5. Three Domains of Life (Six Kingdom Classification) — 1990

The **three-domain system** is a biological classification which was introduced by **Carl Woese**, a professor in the Department of Microbiology, University of Illinois, Urbana-Champaign in 1990 that divides cellular life forms into **archaea, bacteria** and **eukarya** domains. It emphasizes the separation of prokaryotes into two groups, called *Archaea* and *Bacteria*. Because of their fundamental differences, Woese argued that each of the two arose separately from an ancestor with poorly developed genetic machinery, often called a **progenote**.

Infact the three-domain system is loosely based on the traditional five-kingdom system but divides the Monera into two "domains", leaving the remaining eukaryotic kingdoms in the third domain.

It is actually a **six kingdom classification.**

1. **Domain Archaea.** This domain contains prokaryotic organisms which have a monolayer core of lipids in the cell membrane and distinct nucleotides in their 16S RNA. It contains a single kingdom.

Kingdom Archaebacteria. This kingdom contains early prokaryotes which live in extreme environments, *e.g.*, (i) Methanogens— metabolize hydrogen and carbon dioxide into methane. (ii) Halophiles — live in salt. (iii) Thermoacidophiles — live in acid and high temperatures (upto 110°C). (iv) Lokiarchaeota — Discovered from a hydrothermal vent, it has a number of genes similar to eukaryotes (Spang *et al*, 2015) and are considered to be link between procaryotes and eukaryotes.

2. **Domain Bacteria.** This domain contains typical prokaryotes which lack membrane covered cell organelles but do have a sort of microchambers for separating various activities. There is a single kingdom.

Kingdom Eubacteria. The kingdom contains diverse types of bacteria having peptidoglycan cell wall, glycogen as food reserve, naked DNA coiled to form nucleoid, absence of sap vacuoles and presence of 70S ribosomes. Some common groups are bacteria, mycoplasma, actinomycetes, rickettsiae, spirochaetes, firmicutes, cyanobacteria.

3. **Domain Eukarya .** This domain contains eukaryotic organisms which originated by endosymbiotic association between some archaebacteria and eubacteria. It has four kingdoms — Protista, Fungi, Plantae and Animalia.

STATUS OF VIRUSES

Virus (L. poison) *is a nucleoprotein entity which is able to utilize the synthetic machinery of a living cell of another organism for its multiplication which does not involve growth and division.* Even before its discovery a lot of work had been done on virus. Small pox and polio are two viral diseases known since pre-historic times. Broken Tulip (a symbol of love and nicety) was a product of viral infection which was transferable from one variety to another (Causius. 1576). Jenner (1796) discovered vaccination against small pox. Pasteur (1880) found rabies to be infectious disease and produced anti-rabies vaccine. He also coined the term virus before its scientific discovery.

Mosaic disease of Tobacco (Mayer, 1886) was found to be caused by a filterable agent present in the extract of diseased tobacco plant by Ivanowski (1892). He is credited with the discovery of virus. Beijerinck (1896) called it '*contagium vivum fluidum*' (living infectitious fluid). Virus was seen under light microscope by Takahashi and Rawlins (1933) and under electron microscope by Stanley (1946). Stanley (1935) crystallised Tobacco Mosaic Virus (TMV) for the first time. Nucleoprotein nature of virus was discovered by Bawden and Pirie (1936). Polio virus was cultured for first time in human cells by Enders (1949). Virus cannot grow on nonliving culture medium. It requires living cells for its 'metabolism' and multiplication. Hershey and Chase (1952) confirmed that DNA is genetic material in bacteriophages. Franklin Conrat (1956) and later Gierere and Schramm (1956) found RNA to be genetic material in Tobacco Mosaic Virus (TMV). Sinsheimer (1959) observed the presence of single stranded DNA in bacteriophage $\phi \times 174$. Retroviruses were discovered by Temin (1970).

Virus is obligate parasite. It is inert outside the host cell. An inert virus is called **virion.** It can be crystallised and stored indefinitely. A biosynthetic machinery is absent. There is no system to liberate energy. A virus does not grow. It does not divide or reproduce like typical organisms. Instead it multiplies by independent formation of its parts using host machinery and then assembly of parts to produce virus particles. A virus lacks irritability and motility. It requires a vector for transfer from one host to another. Virus having an arthropod as vector or intermediate host is called **arbovirus.**

Size. Virus is the smallest entity. Size varies from 10 nm (Foot and Mouth Virus of Cattle), 17 nm (Alfalfa Mosaic Virus), 300 × 17.5 nm (in TMV), 400 nm (Parrot Fever Virus), 1250× 40 nm (Beet Yellow Virus), 1300 × 6 nm (*Pseudomonas Pf*). Very large viruses upto 1 μm size with upto 2500 genes have been discovered by Claverie and Abergel (2013), *e.g.*, *Megavirus*. Some genes present in these viruses are connected with sugar, lipid and amino acid metabolism. These metabolic genes are not found in other viruses.

Shape. Three architectural forms are found in viruses— **helical** (elongate body, *e.g.*, TMV), **cuboidal** (short broad body with rhombic, rounded, polyhedral shape, *e.g.*, Poliomyelitis virus) and **binal** (with both cuboidal and helical parts, *e.g.*, many bacteriophages like T_2).

Classification. Genetic material is either DNA or RNA. Accordingly viruses are divided into two groups: (a) **Deoxyvira** or DNA viruses. All the three structural forms are known— deoxyhelica, deoxycubica and deoxybinala. (b) **Ribovira** or RNA viruses. They are of two types, ribohelica and ribocubica. Most of the animal viruses are DNA viruses with a few important ones having RNA, *e.g.*, Rabies Virus, Polio Virus, retroviruses including HIV or AIDS virus. Most of the plant viruses are RNA-viruses with a few having DNA (*e.g.*, Cauliflower Mosaic Virus). Bacteriophages have commonly double stranded DNA but all other genome types also occur.

Types. Viruses are host specific. Holmes (1948) has divided viruses into three groups: (a) **Plant Viruses (Phytophagineae).** They cause disease in plants, *e.g.*, Tobacco Mosaic

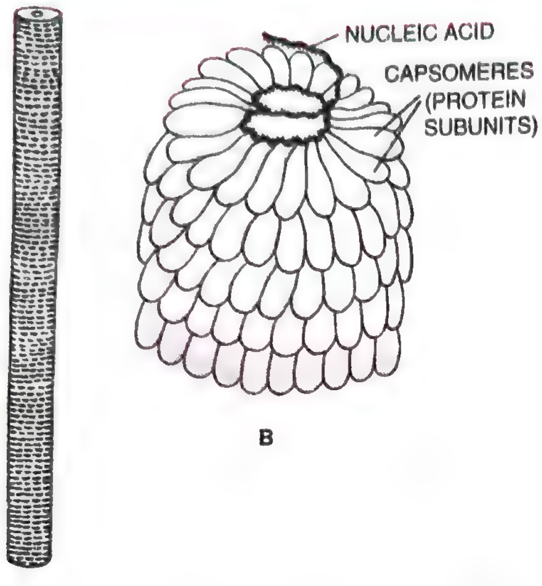


Fig. 2.2. TMV or Tobacco Mosaic Virus. A, external view. B, same broken to show nucleic acid core (nucleoid) and capsid made of protein subunits.

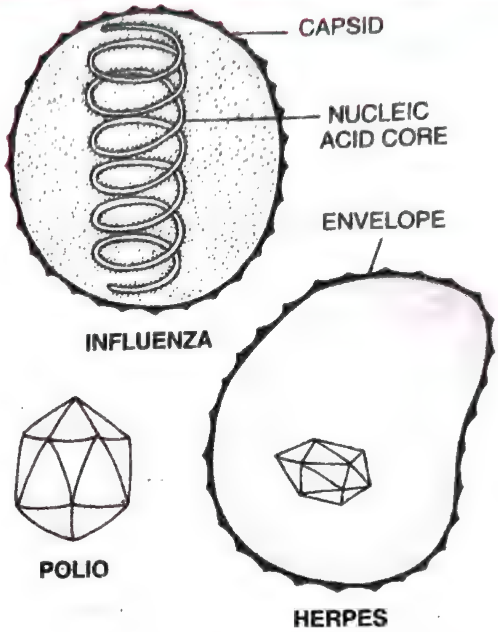


Fig. 2.3. Three animal viruses.

Virus (Fig. 2.2); Potato Mosaic Viruses, Banana Bunchy Top Virus, Tomato Leaf Curl Virus. (b) **Animal Viruses (Zoophagineae,** Fig. 2.3). They parasitise animals including human beings, *e.g.*, Poliomyelitis Virus, Influenza Virus, Small Pox Virus, Hepatitis Virus, Mumps Virus, Rhino Viruses (common cold viruses), H1N1 (Swine Flu Virus), H5N1 (Bird Flu Virus), Ebola Virus, SARS virus. (c) **Phagineae**. They parasitise lower organisms—**bacteriophages** (bacterial viruses, *e.g.*, T_2, T_4, lambda, Fig. 2.4), **coliphages** (bacteriophages of *Escherichia coli*), **cyanophages** (blue-green algal viruses, *e.g.*, LPP-1, SM-1, N-1), **phycophages** (algal viruses), **mycophages** (fungal viruses), **zymophages** (mycophages of yeast).

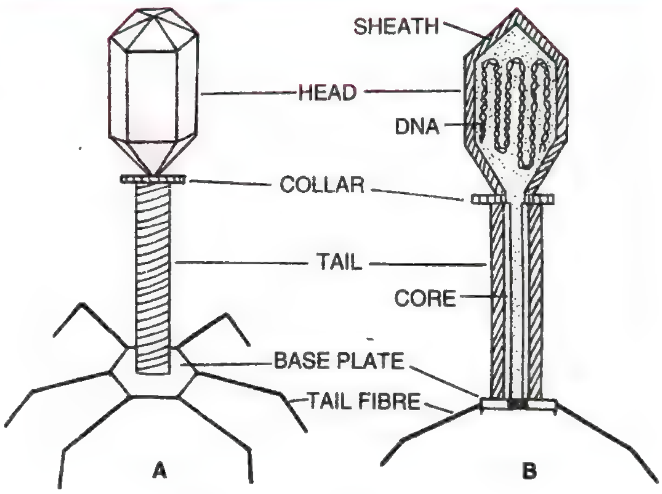


Fig. 2.4. Structure of bacteriophage T_2 external ; B, section of the phage.

Components

A virus consists of two parts— nucleoid (genome) and capsid. An envelope is present in some cases. A few enzymes are also known to occur occasionally inside the virus.

1. **Nucleoid.** It represents the viral chromosome. Nucleoid or viral chromosome is made of a single molecule of nucleic acid. It may be linear or circular with various degrees of coiling. Nucleoid is the infective part of virus. The nucleic acid is either DNA or RNA but never both. DNA containing viruses are called **deoxyviruses** while RNA-containing viruses are termed as **riboviruses**. Each of them has two subtypes, double stranded and single stranded.

(i) **Double Stranded or dsDNA.** It occurs in T_2, T_4 bacteriophages, coliphage Lambda,

Cauliflower Mosaic, Pox Virus, Adenovirus, Herpes Virus (linear), Polyoma Virus, Simian Virus-40 (SM40), Hepatitis B (circular).

(ii) **Single Stranded or ssDNA.** Coliphage MS 2, Coliphage *fd* (linear), Coliphage $\phi \times 174$ (circular). The single strand of DNA is called plus strand. A complementary or negative strand DNA is synthesised to produce DNA duplex for replication during multiplication of virus.

(iii) **Double Stranded or dsRNA.** It is found in Reovirus and Tumour Virus (both linear).

(iv) **Single Stranded or ssRNA.** The condition is more common in riboviruses. The single strand RNA is generally linear. *e.g.*, Poliomyelitis Virus, Foot and Mouth disease Virus, Influenza Virus, Tobacco Mosaic Virus (TMV), Tobacco Necrosis Virus, Potato Mosaic Virus, Bean Mosaic Virus, Retroviruses. **Retroviruses** have two copies of single stranded RNA (hence diploid), *e.g.*, HIV (Human Immunodeficiency Virus, HTLV-III, AIDS Virus), HTLV-1, HTLV-11 (Human T-lymphotrophic Viruses), Rous Sarcoma Virus (RSV of Mouse). In some riboviruses, the RNA can directly function as template and take part in replication (*e.g.*, TMV, Influenza Virus, Paramyxo Virus). In other riboviruses, the RNA of the nucleoid is first employed in synthesising complementary DNA through reverse transcription (*e.g.*, Oncogenic Viruses, HIV). Because of the latter, these viruses are called retroviruses.

The viral chromosome or nucleoid does not contain many genes. T_4 bacteriophage contains about 100 genes. Viral chromosome or nucleic acid is coiled with the help of some polyamines or internal proteins.

2. **Capsid** (Sheath, Coat). It is the proteinaceous covering around the virus which protects the nucleoid from damage from physical and chemical agents. The capsid consists of a number of subunits called **capsomeres** or **capsomers**. The capsid of TMV has 2130 capsomeres. In binal bacteriophages the capsid sheath of tail is contractile.

3. **Envelope.** It is a loose membranous covering that occurs in some animal viruses, rarely plant and bacterial viruses. In contrast to enveloped viruses, the viruses without an envelope are called **naked**. Envelope consists of proteins from (virus), lipids and carbohydrates (from host). It has subunits called **peplomeres** or **peplomers**. Surface of envelope can be smooth or have outgrowths called **spikes**. Common enveloped viruses are HIV, Herpes Virus, Vaccinia Virus, etc.

4. **Enzymes.** They are occasional. Enzyme lysozyme is present in the region that comes in contact with host cell in bacteriophages. Other enzymes are neuraminidase in Influenza Virus, RNA polymerase, RNA transcriptase, reverse transcriptase.

Reproduction

It is of two main types, **phagic** and **pinocytic**. In pinocytic reproduction, the whole virus (except envelope, if present) passes into host cell. In phagic reproduction, only the nucleoid enters the host cell. Phagic reproduction has two sub-types, lytic and lysogenic.

1. **Lytic Cycle** (Fig. 2.5). It is the reproductive cycle of virulent phages, *e.g.*, T_4 bacteriophage. The phage attaches itself to the host cell (*e.g., Escherichia coli*) through its tail fibres. The fibres bend and bring the tip of tail in contact with the host cell wall. The tip of the tail produces a hole in the bacterial cell wall by means of enzyme lysozyme. The tail sheath contracts and injects the viral genome into host cell. After entering the host cell, the viral DNA transcribes some early mRNAs to form some enzymes over the host ribosomes. Some of these are nucleases. They degrade host DNA and mRNAs. Ribosomes and tRNAs remain unaffected. Phage DNA and mRNA are also protected from nucleases due to

methylation of their **cytosine bases**. Parent viral DNA functions as a template and replicates repeatedly with the help of bacterial nucleotides. Simultaneously, host machinery (ribosomes, tRNAs, amino acids, energy) is used by phage genes to synthesise proteins for viral lysozyme, internal proteins and capsid proteins. Different components combine to form new viruses or phage particles. The host cell ruptures by means of lysozyme releasing the phage particles. The period between entry of viral nucleoid into host cell and bursting of host cell to release new viruses is called **eclipse period**.

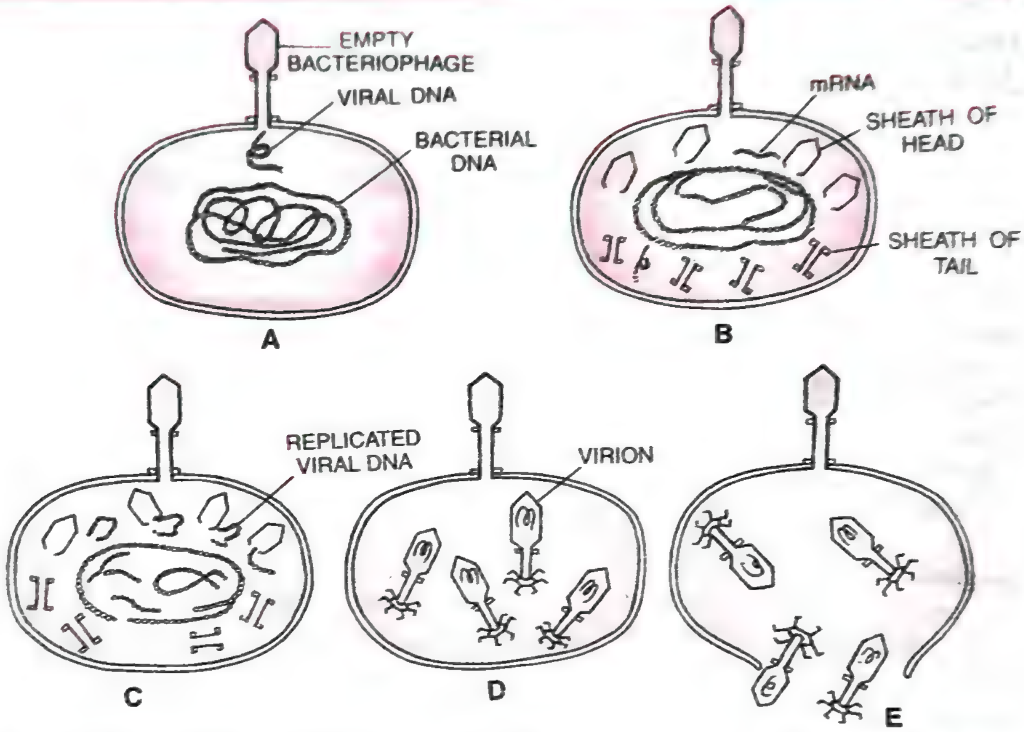


Fig. 2.5. Lytic cycle in bacteriophage T_4. A, injection of viral DNA. B, formation of proteins. C, replication of viral DNA. D, synthesis of new bacteriophages. E, lysis of the bacterium and release of bacteriophages.

2. **Lysogenic Cycle** (Fig. 2.6). Lambda phage (λ phage) has a higher degree of regulation of its genes. The phage is parasitic over *Escherichia coli*. It does not possess tail fibres for attachment to bacterial cell. The tail directly comes in contact with bacterial cell, drills a hole in the wall and injects the phage DNA into the cell. In lysogenic cycle,the phage DNA does not take over the control of cellular machinery of the host. Instead, it produces a **repressor** (*e.g.*, cI) and undergoes reduction to

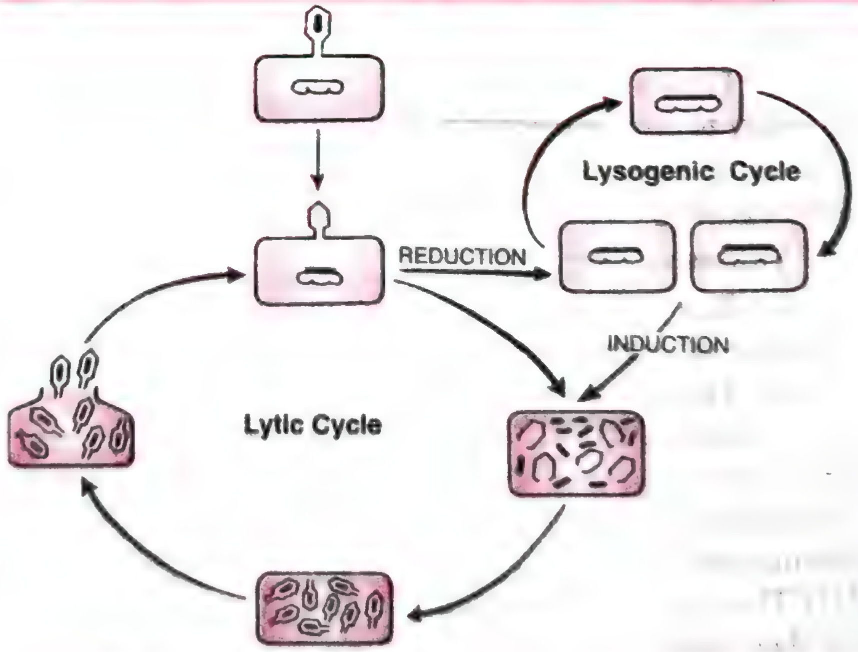


Fig. 2.6. Lysogenisation in lambda phage reproduction.

temperate or **nonvirulent state**. With the help of enzyme **integrase** the viral genome becomes integrated with the chromosomal DNA of the bacterium at a specific site (*e.g.*, galactose locus in λ phage). In this form the viral genome is called **prophage**. Prophage replicates along with bacterial chromosome and, therefore, gets distributed to the daughter bacteria. Prophage does not form virus particles because the genes connected with taking over of host machinery remain repressed due to formation of a repressor. At times the synthesis of repressor is stopped. Repressor can also be destroyed by chemicals, high energy radiations and other adverse conditions. This converts the temperate or non virulent virus into **virulent** or **lytic virus**. Therefore, the bacterial cell carrying prophage is called **lysogenic cell** and the phenomenon of existence of virus genome in prophage state alongwith host DNA is termed as **lysogeny**.

Differences Between Lysogenic and Lytic Phases of a Virus

Lysogenic Phase	*Lytic Phase*
1. The viral genome or its complementary DNA gets integrated with the host DNA. It is called prophage or provirus.	1. The viral genome does not integrate with host DNA.
2. The host DNA is not hydrolysed during lysogenic phase.	2. The host DNA is often hydrolysed in the lytic phase.
3. The prophage or provirus replicates only once along with the replication of host genome so that a single particle is transferred to a daughter cell.	3. The viral genome replicates repeatedly and forms a number of copies in the same host cell.
4. The cellular machinery of the host is only slightly disturbed.	4. The cellular machinery of the host iscompletely taken over by the viral genome.
5. The virus is non–virulent or temperate.	5. The virus is virulent.
6. The host cell does not get lysed.	6. The host cell undergoes lysis.
7. Virus particles are liberated only rarely.	7. A number of virus particles are liberated when the host cell becomes lysed.

Viruses are intermediate between living and nonliving entities. They resemble non-living objects in—

(1) Lacking protoplast. (2) Ability to get crystallized, *e.g.*,TMV, poliomyelitis virus. (3) Inability to live independent of a living cell. (4) High specific gravity which is found only in non-living objects. (5) Absence of respiration. (6) Absence of energy storing system. (7) Absence of growth and division. Instead different parts are synthesised separately.

Viruses resemble living beings in—

(1) Being formed of organic macromolecules which occur only in living beings. (2) Presence of genetic material. (3) Ability to multiply or reproduce. (4) Occurrence of mutations. The most mutable virus is HIV or AIDS (Acquired Immune Deficiency Syndrome) virus followed by Influenza virus. (5) Occurrence of enzyme transcriptase in most viruses. (6) Some viruses like Pox virus contains vitamins like Riboflavin and Biotin. (7) Occurrence of antigenic properties. (8) Infectivity and host specificity. (9) Viruses are 'killed' by autoclaving and ultraviolet x-rays. (10) They breed true to their type. Even variations are inheritable. (11) They take over biosynthetic machinery of the host cell and produce chemicals required for their multiplication. (12) Viruses are responsible for a number of infectious diseases like common cold, epidemic influenza, chicken pox, mumps, poliomyelitis, rabies, herpes, AIDS, etc.

Viroids (L. *virus*– poison, *eidos*– diminutive)

They are the smallest self replicating particles which were discovered by Diener (1971). Viroids are infectious RNA particles which are devoid of protein coat. They are obligate parasites. Molecular weight of a viroid is low. The RNA is tightly folded to form circular or linear structure. Viroids are known to cause diseases (some 20) in plants only. *e.g.*, Potato spindle tuber, chrysanthemum stunt. Animal or human infection is not known. Viroid does not produce a protein as it does not possess an initiation codon. The mechanism of disease production is not very clear. Viroid particle can multiply by both RNA dependent and DNA dependent replication.

Differences between Virus and Viroid

Virus	*Viroid*
1. It is a nucleoprotein particle.	1. It is an RNA particle.
2. Nucleic acid can be DNA or RNA.	2. Viroid is formed of only RNA.
3. A protein covering or coat is present.	3. A protein coat is absent.
4. Virus has a larger size.	4. Viroid has a smaller size.
5. Virus is known to infect all types of organisms.	5. Viroid is known to infect only plants.

Viral Diseases

1. **Plant Viral Diseases.** Potato mosaic, Pumpkin mosaic, Apple mosaic, Tulip mosaic (Broken Tulip), Bhindi yellow vein mosaic, Potato Leaf roll, Papaya leaf curl, Banana bunchy top, Tomato bunchy, Rice tungro.

2. **Animal Viral Diseases.** Foot and mouth, rinderpest, Ranikhet or new castle of fowl, bird flu.

3. **Human Viral Diseases.** Measles, chickenpox, mumps, poliomyelitis, rabies, hepatitis, dengue, encephalilis, AIDS, common cold, flu, herpes, SARS (severe acute respiratory syndrome), bird flu (H5N1), Swine flu (H1N1).

PRIONS (Prusiner, 1983)

They are highly resistant small sized glycoprotein particles which function as infectious agents. They are formed due to mutation in gene *PRNP* that causes changes in three dimensional configuration. Prions can also act as catalyst converting normal protein into prion state. Prions are not affected by proteases, nucleases, temperature upto 800°C, UV radiations and formaldehyde.

Prions accumulate in nervous tissue and bring about its degeneration. Common diseases caused by them are scrapie of sheep, mad cow disease, Cruetzfeldt-Jakob disease (CJD) and kuru.

In fungi, prions have a defensive role against antibiotics and toxins (Halfman and Lindaquest 2010).

ADDITIONAL INFORMATION

- **Cladistics.** Systematic classification based on evolutionary relationships of organisms in order of their assumed divergence from ancestral forms.
- **Adansonian Taxonomy.** Numerical taxonomy is also called Adansonian taxonomy because it was first attempted by Adanson (1763).
- **Karyotaxonomy.** Taxonomy based on inter-relationships developed on the basis of characteristics of nucleus and chromosomes.
- **Bird Flu.** Avian influenza which spreads to humans as well.
- **Turril** (1938). He has divided taxonomic studies into three phases– α, β and ω.

- **α-Taxonomy**. Taxonomy based on gross morphological features.
- **β-Taxonomy**. Taxonomy based on morphology, anatomy, cytology, embryology, biochemistry and other branches of study.
- **ω-Taxonomy**. Neosystematics or biosystematics which is based on all types of evidences including experimental, genetic and evolutionary.
- **Takhtajan**. Taxonomy without phylogeny is bones without flesh.
- **Twort** (1915). Discovered virus-infecting bacteria. They were named **bacteriophages** by Herelle (1917).
- **Delbruck** (1938). Found viruses to undergo mutations.
- **Lwoff** (1953). Discovered temperate cycle in viruses.
- **Saffarman and Morris** (1963). Discovered cyanophages.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Discuss how classification systems have undergone several changes over a period of time.

   ✓ Classification systems are procedures of arranging organisms into groups and subgroups on the basis of similarities and dissimilarities of certain characters. The earliest systems were artificial. Then came natural systems, phylogenetic and now phenetic systems.

   Artificial Systems of Classification. Refer to the text.
   Natural Systems of Classification. Refer to the text.
   Phylogenetic System of Classification. Refer to the text.
   Phenetic System of Classification. Refer to the text.

2. Give a brief account of viruses with respect to their structure and nature of genetic material. Also name four common viral diseases.

   ✓ For Structure, Nucleoid, Capsid, Envelope, Enzymes — Refer to the text.

   Genetic Material. Nucleoid represents the genetic material of virus. It is also the infective part of virus. Genetic material can be **double stranded DNA** (*e.g.*, T_2, T_4 bacteriophages, Herpes virus, Hepatitis B), **single stranded DNA** (*e.g.*, Coliphase $\varphi \times 174$), **double stranded RNA** (*e.g.*, Reovirus, Tumour virus) and **single stranded RNA** (*e.g.*, TMV, Foot and Mouth Virus, Polio Virus, retroviruses). Retroviruses synthesize complementary DNA through reverse transcriptase (*e.g.*, HIV). Others have RNA → RNA replication.

   Viral Diseases. Dengue, SARS, AIDS, Potato mosaic.

3. Organise a discussion in your class on the topic — Are viruses living or nonliving ?

   ✓ Viruses resemble living beings in some characteristics. However, many characteristics of living beings are absent in them.

   Characters of Living Beings. (i) Occurrence of genetic material. (ii) Presence of mutations. (iii) Ability to multiply. (iv) Daughter viruses resemble parent viruses. (v) Viruses are host specific. (vi) They have antigenic properties. (vii) Enzymes are known in a few viruses. (viii) Ability to control cellular machinery of the host. (ix) Viruses are obligate parasites. Viruses are killed by UV radiations, autoclaving and many disinfectants. (xi) They follow particular pattern of life cycle and reproduction.

   Characters of Nonliving Beings. (i) Absence of cellular structure. (ii) Absence of metabolic machinery. (iii) Absence of energy storing and energy liberating systems. (iv) There is no growth. (v) A virus does not divide. (vi) Multiplication occurs by synthesis of parts and then their assembly like those of machines. (vii) Irritability is absent. (viii) Movements are absent. (ix) Viruses are inert outside the host cells. (x) They can be crystallised.

   Conclusion. Viruses are obligate parasites where different cellular structures have degenerated due to overtaking of metabolic machinery of host.

4. Plants are autotrophic. Can you think of some plants that are partially heterotrophic ?

   ✓ Insectivorous or carnivorous plants are partially heterotrophic autotrophs. They are green and autotrophic. However, they augment their nitrogen supply by catching and digesting small animals.

   Examples. *Utricularia, Drosera, Nepenthes.*

5. How are viroids different from viruses ?

   ✓ Refer to the text for the differences.

TEST QUESTIONS

One Mark Questions (Some With Answers)

1. What is cytotaxonomy ?
   ✓ It is classification based on number, structure and behaviour of chromosomes and various other comparative cytological studies.
2. Define chemotaxonomy.
   ✓ It is system of classification that studies various chemical constituents of organisms so as to find out their similarities, affinities and dissimilarities.
3. What is artificial system of classification ?
   ✓ It is a system of classification based on one or a few characters of habitat and morphology which do not indicate their natural relationships.
4. What do you mean by natural system of classification ?
   ✓ System of classification based on the study of a number of characters which help in grouping of organisms in a such a way as to bring out their natural similarities and dissimilarities.
5. Define phylogenetic classification.
   ✓ It is system of classification which endeavorus to group organisms in such a way as to bring out their evolutionary relationships.
6. What is phenetic classification ?
   ✓ It is a system of phylogenetic classification which deals with affinities, similarities and dissimilarities of characteristics found in only living organisms.
7. Define cladistics.
   ✓ It is system of taxonomy that arranges organisms on the basis of their shared derived characters.
8. Define numerical taxonomy ?
   ✓ It is type of taxonomy which evaluates resemblances and differences or primitiveness and advancement through statistical methods based on a large number of characters obtained from all disciplines of biology followed by computer analysis. It establishes the numerical degree of relationship among **individuals**.
9. Name the different kingdoms proposed by Whittaker.
   ✓ Monera, Protista, Plantae, Fungi and Animalia.

Two Mark Questions (With Sample Answers)

1. Name two features of procaryotes, one of which should be about genetic material.
   ✓ Procaryotes have a naked genetic material without being organised into a nucleus, a single envelope organisation, absence of spindle apparatus, meiosis and sexual reproduction.

Three Mark Questions (Without Answers)

1. Distinguish between cytotaxonomy and chemotaxonomy.
2. Numerical taxonomy is likely to furnish more reliable and stable information on the relationships of taxa for classification. Discuss.
3. Give the main differences between natural and phylogenetic systems of classification.
4. Define absorptive and holozoic nutrition.
5. What is artifical system of classification ? List the difficulties in adopting the system.
6. Highlight the criteria used for five kingdom system of classification.
7. Differentiate briefly the characteristics of kingdom Plantae and Animalia.
8. What is two kingdom classification ? Give its drawbacks.
9. Compare the salient features of Monera with Protista.

Five Mark Questions (Long Answer Type)

1. Make an outline of the five-kingdom classification. What are the advantages and disadvantage of this classification ?
2. Describe the important characters of kingdom Plantae.
3. Explain the distinguishing features of Animalia.
4. Write the distinct characters of fungi.
5. Draw well labelled diagram of (i) Bacteriophage (ii) TMV.

Multiple Choice Questions

(1) Living beings have been divided into the three domains. What is true of archaea (a) Completely differ from protraryotes (b) Resemble eukaryotes in all respects (c) It has novel features absent in prokaryotes and eukaryotes (d) Completely differ from prokaryotes and eukaryotes. *(CBSE 2008)*

(2) A kingdom common to unicellular plants and animals is (a) Monera (b) Protista (c) Fungi (d) Plantae. *(DPMT 2009)*

(3) Diener discovered (a) Free infectious protein (b) Free infectious DNA (c) Free infectious RNA (d) Bacteriophage. *(CBSE 2009)*

(4) Basic unit of classification is (a) Genus (b) Species (c) Variety (d) Family. *(HP PMT 2012)*

(5) Holotype is (a) specimen used by the person as nomenclatural type (b) duplicate of the nomenclatural type (c) specimens mentioned while describing a new taxa on which the description is not based (d) specimens of a taxa deposited by different workers. *(Chandigarh CET 2012)*

(6) A virus can be considered living as it (a) Reproduces inside the host (b) Can cause disease (c) Responds to touch stimuli (d) Respires. *(JK CET 2013)*

(7) Which one of the living organisms completely lacks a cell wall (a) Sea Fan (b) *Saccharomyces* (c) Blue-green algae (d) Cyanobacteria. *(CBSE 2014)*

(8) In five Kingdom classification, single celled eukaryotes are included in
(a) Fungi (b) Protista (c) Monera (d) Archaea. *(J&K CET 2015)*

(9) In Vedic times, living organisms were classified into following number of classes
(a) 2 (b) 3 (c) 4 (d) 5. *(Bihar CECE 2015)*

(10) Enzymes are not found in (a) Fungi (b) Cyanobacteria (c) Viruses (d) Algae. *(Uttarakhand 2015)*

(11) Which is wrong for viroids (a) RNA is of high molecular weight (b) they lack a protein coat (c) they are smaller than viruses (d) they cause infections. *(NEET 2016)*

(12) Nomenclature is governed by certain universal rules. Which one of the following is contrary to the rules of nomenclature ? (a) The first word in a biological name represents the genus name and the second is a specific epithet (b) The names are written in Latin and are italicised (c) When written by hand, the names are to be underlined (d) Biological names can be written in any language. *(NEET-I-2016)*

(13) Methanogens belong to (a) eubacteria (b) archaebacteria (c) dinoflagellates (d) slime moulds. *(NEET-II-2016)*

(14) Viroids differ from viruses in having (a) DNA molecules without protein coat (b) RNA molecules with protein coat (c) RNA molecules without protein coat (d) DNA molecules with protein coat. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as

(a) If both A and R are true and R is the correct explanation of A
(b) If both A and R are true and R is not correct explanation of A
(c) If A is true but R is false.
(d) If both A and R are false.

(1) **Assertion :** Severe acute respiratory syndrome (SARS) origin in China.
Reason : China is the most populated country of the world.
A B C D *(AIIMS 2003)*

ANSWERS

Multiple Choice Questions

(1) —c (2) —b (3) —c (4) —b (5) —a (6) —a (7) —a (8) —b (9) —b (10) —c
(11) —a (12) —d (13) —b (14) —c

Assertion and Reason Type Questions

(1) —B

2A KINGDOM MONERA

Monera is a kingdom of procaryotes. Therefore, it is also known as **procaryota.** It includes the most primitive forms of life which developed from an early stock known as **progenote**. Being the earliest forms of life, monerans are adapted to all types of habitats. Population wise they are the most numerous of all organisms. They are found everywhere, wherever organic matter can be present or can be supported— ocean bottoms, below icebergs, hot springs, dry deserts, dust particles, inside and outside the body of other organisms. The air we breathe in contains thousands of these organisms generally in their spore stage, in which form they are dispersed. A teaspoon full of soil contains more monerans than the human population in India.

Monerans have very little morphological differentiation. Therefore, it is very difficult to distinguish groups, subgroups, genera and species on the basis of structural and morphological characters alone. Many other characters are taken into consideration while classifying monerans. They include besides morphological characters, biochemical, physiological and ecological characters. Molecular homology is being increasingly used in delimiting different taxa. One of these is comparing nucleotide sequence on ribosomal RNAs. With the help of molecular homology it has been found out that archaebacteria are the most primitive of all the monerans. For studying these details monerans are raised in **pure cultures** in which progeny of a single individual is reared in artificial medium without any contamination.

Important characteristics of kingdom monera are listed in Chapter 2.

There are two major groups of monerans, **archaebacteria** (ancient bacteria) and **eubacteria** (true bacteria). Eubacteria is of further two types; bacteria and cyanobacteria. Some other groups of monerans are mycoplasma, rickettsiae and actinomycetes.

Bacteria

Bacteria are a group of procaryotic organisms or monera which is characterised by peptidoglycan wall, a compacted but naked DNA with attached mesosome and reserve food made of glycogen and fat. Bacteria were discovered by Leeuwenhoek in 1676. They have the following traits (Fig. 2.9) :

(a) Basically unicellular form.
(b) Peptidoglycan cell wall.
(c) Mucilage covering.
(d) Procaryotic organisation with naked circular DNA folded to form nucleoid.
(e) Nucleoid attached to a membranous structure called mesosome by a Y-shaped fork.
(f) Sap vacuoles absent. Instead, gas vacuoles occur in a number of cases.
(g) Membrane covered cell organelles, including endoplasmic reticulum, are absent.
(h) Ribosomes are 70S in nature.
(i) Binary fission is the mode of multiplication.

(j) Varied nutrition including photoautotrophic, saprotrophic, parasitic and chemoautotrophic. Photoautotrophic forms possess bateriochlorophyll instead of typical chlorophyll.

(k) Flagella, if present, are single stranded. They are made of protein called flagellin.

Occurrence. Bacteria are the most abundant microorganisms. A handful of soil may contain hundreds and thousands of them. They are ubiquitous, being found in all places where organic matter is present— in water, air, soil, over and inside the bodies of various organisms. They can tolerate extreme environments like hot springs, frozen waters, deserts, deep oceans, acidic, alkaline and saltish conditions.

Structure of a Bacterial Cell

It is a prokaryotic cell in which genetic material is not organised in the form of nucleus but instead lies freely in a naked super-coiled state in the cytoplasm whence it is known as **prochromosome** or **nucleiod**. Prokaryotic (= eukaryotic) cells are known for their rapid multiplication. The average size is 2.0–2.6 μm long and 1.1–1.5 μm wide. The smallest bacterial cells are 100–200 nm (0.1–0.2 μm). The smallest bacterium is *Dialister pneumosintes*. It has a size of 0.15 μm. The largest bacterial cells belong to spirochaetes and blue green algae. Here the cell may reach a size of 500 μm. *Epulopscium fishelsoni*, a bacterium found in the intestine of Brown Surgeon Fish is 600μm long and 80 μm wide. Marine bacterium *Thiomargarita ramibiensis* is 750 μm long. Therefore, some bacterial cells are quite large as compared to eukaryotic cells (5–100 μm).

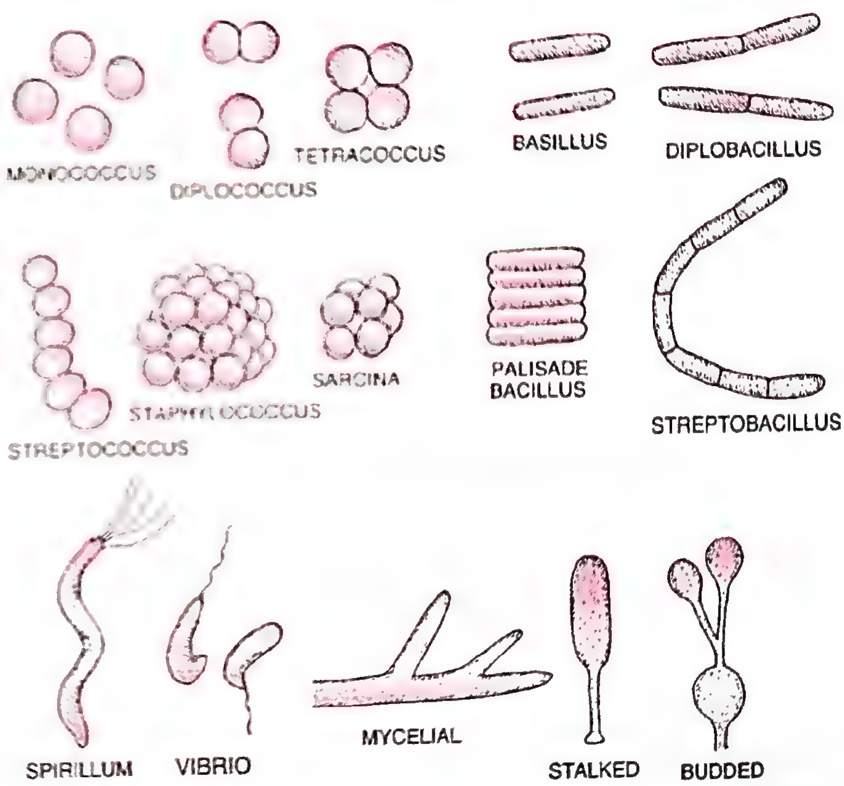


Fig. 2.7. Various forms of bacteria.

In shape, bacterial cells are of many types (Fig. 2.7). Mycelial form is found in actinomycetes.

1. **Coccus** (Gk. *kokkos*– berry). Coccus bacteria are spherical or ovoid in outline. Depending upon their grouping they are called (i) **Monococcus** (occurring singly), (ii) **Diplococcus** (in twos), (iii) **Tetracoccus** (in tetrads), (iv) **Streptococcus** (in chains), (v) **Staphylococcus** (irregular grape-like clusters) and (vi) **Sarcina** (3-dimensional geometrical forms).

2. **Bacillus** (L. *bacillus*– small rod). The bacterium is straight and cylindrical like a rod with ends being flat, rounded or cigar shaped. It has three special types : (i) **Diplobacillus** (in twos), (ii) **Palisade Bacillus** (like a stack) and (iii) **Streptobacillus** (in chains).

3. **Spirillum** (L. *spira*– coil). The bacterium is coiled like a cork-screw, *e.g.*, *Spirillum*, *Spirochaete*. Aggregation does not occur.

4. **Vibrio**. The body of the bacterium is like a comma, curved rod or single turn of the spiral *e.g.*, *Vibrio cholerae*. Like spirillum bacteria, the vibrio forms live singly.

5. **Stalked**. The bacterium possesses a stalk, *e.g.*, *Caulobacter*.

6. **Budding**. The bacterium is swollen at places, *e.g.*, *Rhodomicrobium*.

Flagellation (Fig. 2.8).

Depending upon the presence or absence of flagella, bacteria are grouped into flagellate and nonflagellate types. The various forms of flagellation (Fig. 2.9) are as follows :

(a) **Atrichous.** Flagella absent.

(b) **Monotrichous**. A single flagellum occurs at or near one end of bacterium.

(c) **Amphitrichous**. A flagellum at each of the two ends.

(d) **Lophotrichous**. A group or tuft of flagella is found only at one end.

(e) **Cephalotrichous**. A tuft or group of flagella occurs at each of the two ends or poles. Many authors use the term **amphitrichous** for both single flagellum and tuft of flagella at each end.

(f) **Peritrichous**. A number of flagella are distributed all over the surface.

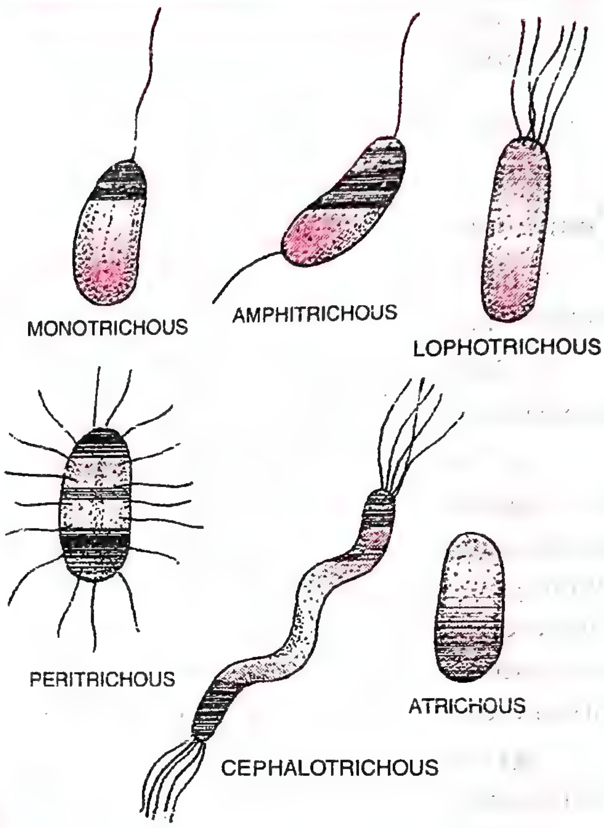


Fig. 2.8. Flagellation types in bacteria.

Gram Positive and Gram Negative Bacteria

The grouping is based on the reaction of bacteria to **Gram's stain** (Christian Gram, 1884). Bacteria are stained first with weakly alkaline solution of crystal violet or gentian violet, when all of them pick up blue colour. They are then treated with 0.5% iodine solution followed by washing with water and then absolute alcohol or acetone. Bacteria which retain blue or purple colour are known as **Gram (+) bacteria** (*e.g.*, *Bacillus subtilis*). Bacteria which do not retain any stain and become colourless are termed as **Gram (–) bacteria** (*e.g.*, *Escherichia coli*). (Gram–ve bacteria are commonly stained with safranin). Washing of the stain in Gram –ve bacteria is due to high lipid content of cell wall which gets dissolved in organic solvents like acetone.

Differences between Gram +*ve* and Gram-*ve* Bacteria

Gram +ve Bacteria	*Gram–ve Bacteria*
1. They remain coloured blue or purple with Gram stain even after washing with absolute alcohol or acetone.	1. The bacteria do not retain the stain when washed with absolute alcohol.
2. The wall is single layered. Outer membrane is absent.	2. The wall is two layered. Outer membrane is present.
3. The thickness of the wall is 20-80 nm.	3. It is 8-12 nm.
4. The lipid content of the wall is quite low.	4. The lipid content of the wall is 20-30%.
5. The wall is straight.	5. The wall is wavy and comes in contact with plasmalemma only at a few places.

6. Murein or mucopeptide content is 70-80%.	6. It is 10-20%.
7. Basal body of the flagellum has two rings of swellings.	7. Four rings of swellings occur in the basal body.
8. Mesosomes are more promiment.	8. Mesosomes are less prominent.
9. The bacteria are more susceptible to antibiotics.	9. They are more resistant to antibiotics.
10. Fewer pathogenic bacteria belong to Gram +ve group.	10. Most of the pathogenic bacteria are Gram –ve.
11. Porins are absent.	11. Porins or hydrophilic channels occur in outer membrane of cell wall.
12. Cell wall contains teichoic acids.	12. Teichoic acids are absent.

Components of Bacterial Cell (Fig. 2.9)

A bacterial cell consists of a cell envelope, cytoplasm, nucleiod, plasmids, inclusion bodies, flagella, pili and fimbriae.

1. **Cell Envelope**. It is the outer covering of protoplasm of bacterial cell. Cell envelope consists of 3 components— glycocalyx, cell wall and cell membrane.

(i) **Glycocalyx (Mucilage Sheath)**. It is the outermost mucilage layer of the cell envelope which consists of non-cellulosic polysaccharides with or without proteins. Glycocalyx may occur in the form of loose sheath when it is called **slime layer**. If thick and tough, the mucilage covering is called **capsule**. Glycocalyx gives sticky character to the cell. It is not absolutely essential for survival of bacteria. However, it has several secondary functions. (a) Prevention of desiccation. (b) Protection from phagocytes. (c) Protection from toxic chemicals and drugs. (d) Protection from viruses. (e) Attachment. (f) Immunogenicity (g) Virulence.

(ii) **Cell Wall**. It is rigid solid covering which provides shape and structural support to the cell. Cell wall lies between plasma membrane and glycocalyx. **Periplasmic space** occurs between plasma membrane and cell wall. Cell wall protects the bacterial cells against

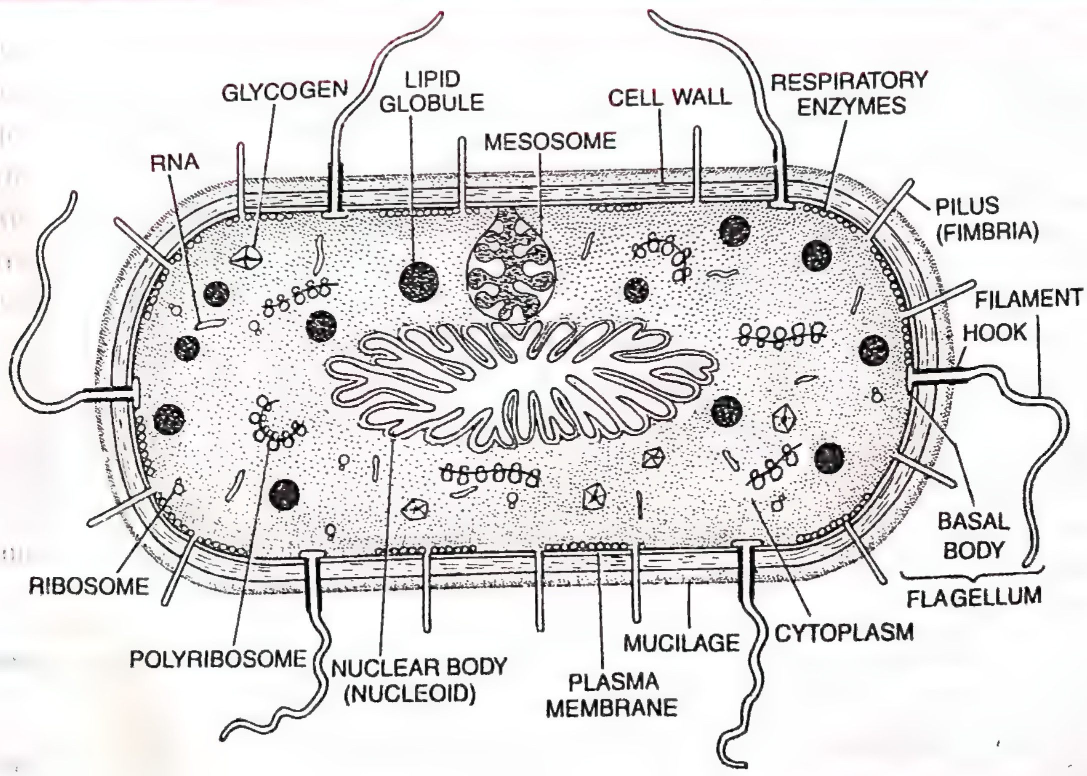


Fig. 2.9. Cell structure under electron microscope (Plasmid and volutin granules not shown)

bursting in hypotonic solution. Wall is 20–80 nm thick in Gram positive bacteria. It is single layered and smooth. In Gram negative bacteria, wall is 8–12 nm thick, complex, wavy and two layered. The outer layer is also called **outer membrane**. It consists of lipopolysaccharides, lipids and proteins. The outer membrane has hydrophilic channels of 16-stranded β-barrel proteins called **porins**. The single layered cell wall of Gram positive bacteria and inner wall layer of Gram negative is made up of pepidoglycan, proteins, non-cellulosic carbohydrates, lipids, amino acids, etc. Peptidoglycan forms the structural network of the cell wall. It is also known as **murein** or **mucopeptide**. Peptidoglycan consists of long glycan strands formed of repeating units of N-acetyl glucosamine (NAG) and N-acetyl muramic acid (NAM). They are cross linked by small peptide chains. Peptidoglycan constitutes 70–80% of wall in Gram positive bacteria. Lipid content is little. 10–20% of wall in Gram negative bacteria is formed of peptidoglycan. Lipid content is 20–30%. Amino acid present in the wall is diaminopimelic acid or lysine. In Gram positive bacteria, the wall contains **teichoic acids** that form receptor sites and surface antigens. In *Mycobacterium* and *Nocardia*, the wall contains long chain fatty acids called **mycolic acids**.

(iii) **Plasma Membrane**. It is selectively permeable covering of the cytoplasm that forms the innermost component of cell envelope. Bacterial plasma membrane or plasmalemma has a structure similar to that of a typical membrane. It is made of a phospholipid bilayer with proteins of various types (extrinsic, integral, transmembrane). It also holds receptor molecules for detection and responding to different chemicals of the surroundings. Bacterial membrane is metabolically active as it takes part in respiration, synthesis of lipids and cell wall components.

2. **Cytoplasm**. It is crystallo-colloidal complex that forms the protoplasm excluding its nucleoid. Membrane bound cell organelles as found in eukaryotes are absent. However, all biochemical pathways are found in prokaryotic cells. Cytoplasmic streaming is absent. Sap vacuoles are absent. Instead gas vacuoles are present. Various structures present in cytoplasm are as follows :

(i) **Mesosome** (Fitz James 1960). It is a characteristic circular to villiform specialisation of cell membrane of bacteria that develops as an ingrowth from the plasma membrane. It consists of vesicles, tubules and lamellae. Mesosme is of two types, septal and lateral. **Septal mesosome** connects nucleoid with plasma membrane. It takes part in replication of nucleoid by providing points of attachment to the replicated ones. Septal mesosome is also believed to help in septum formation. At the time of cell division, plasma membrane grows in the region where the septal mesosme is present so that most probably it provides membranes for rapid elongation. **Lateral mesosme** is not connected with nucleoid. It contains respiratory enzymes and is, therefore, often called **chondrioid**. It is beleived to be equal to mitochondrion of eukaryotes. However, respiratory enzymes are also present over the plasma membrane.

(ii) **Ribosomes.** They are small membraneless, submicroscopic ribonucleoprotein entities having a size of 20 nm × 14–15 nm. Ribosomes are of two types, fixed and free. **Fixed ribosomes** are attached to the plasma membrane. **Free ribosomes** occur free in the cytoplasmic matrix. The ribosomes are 70S in nature. (Here *S* denotes sedimentation coefficient or Svedberg number). Each ribosome has two subunits, larger 50S and smaller 30S. Ribosomes take part in protein synthesis. Free or matrix ribosomes synthesize proteins for intracellular use while fixed ribosomes synthesize proteins for transport to outside. Ribosomes generally occur in helical groups called **polyribosomes** or **polysomes**. In each polysome 4–8 ribosomes are attached to a single strand of messenger or mRNA. It is a mechanism to synthesise several copies of the same protein.

(iii) **Chromatophores**. They occur in photoautotrophic bacteria. In purple bacteria they are covered by a normal membrane, while in green bacteria the chromatophores are

covered by non-unit, non-lipid, protein membrane. Chromatophores of green bacteria are sometimes called **chlorosomes**. Photosynthetic pigments are bacteriochlorophyll, bacteriophaeophytin and carotenoids.

3. **Nucleoid**. It represents the genetic material of prokaryotes. Several alternative names have been given to nucleoid— **genophore, prochromosome, incipient nucleus** and **chromoneme**. Nucleoid consists of a single circular strand of DNA duplex which is super-coiled with the help of RNA and polyamines to form a nearly oval or spherical complex. The folding is 250-700 times. Polyamines or nucleoid proteins are different from histone proteins. DNA of prokaryotes is considered **naked** because of its non-association with histone proteins and absence of nuclear envelope around it. In *E.coli*, nucleoid has 1100 μm long DNA duplex with 4.6×10^6 base pairs. Nucleoid is embedded freely in the cytoplasm. A cell can have 2 or more nucleoids but all are replicated copies of same nucleoid. It is equivalent to a **single chromosome** of eukaryotes because nucleoid consists of a single DNA double strand. Nucleoid may be directly attached to the plasma membrane or through the mesosome.

4. **Plasmids**. They are self replicating, extra chromosomal segments of double stranded, circular, naked DNA. Plasmids provide unique phenotypic characters to bacteria. They are independent of main nucleoid. Some of them contain important genes like fertility factor, nif genes, resistance factors and colicinogenic factors. Plamsids which can get associated temporarily with nucleoid are known as **episomes**. Plasmids are used as vectors in genetic engineering.

5. **Inclusion Bodies**. They are non-living structures present in the cytoplasm. The inclusion bodies may occur freely inside the cytoplasm (*e.g.*, cyanophycean granules, volutin or phosphate granules, glycogen granules) or covered by 2-4 nm thick non-lipid, non-unit protein membrane (*e.g.*, gas vacuoles, carboxysomes, sulphur granules, PHB granules). On the basis of their nature, the inclusion bodies are of 3 types— gas vacuoles, inorganic inclusions and food reserve.

(i) **Gas Vacuoles**. They are gas storing vacuoles found in cyanobacteria, purple and green bacteria and a few other planktonic forms. A gas vacuole is without any covering of its own. It consists of a variable number of hexagonal, hollow and cylindrical **gas vesicles**. Each gas vesicle is surrounded by a single non-unit, non-lipid protein membrane having ribs or folds. The membrane is impermeable to water but is permeable to atmospheric gases. Gas vacuoles protect the bacteria from harmful radiations. They also constitute buoyancy regulation mechanism for their proper positioning in water during daytime for photosynthesis.

(ii) **Inorganic Inclusions.** Several types of inorganic granules occur in bacteria. They include volutin granules, sulphur granules, iron granules, magnetite granules, etc. Because of the ability to pick up different colours with basic dyes, they are called **metachromatic granules**. Two common types of inorganic granules are volutin granules and sulphur granules. Volutin granules are polymetaphosphates which function as storage reserve of phosphate. Sulphur granules occur in bacteria living in sulphur rich medium like the one which pick up hydrogen sulphide for obtaining reducing power in photosynthesis. Iron granules are similarly found in those bacteria which metabolise iron compounds for obtaining energy. *Aquaspirillum magnetotacticum* contains **magnetosomes,** which are vesicles having magnetite. The granules help the bacteria to orientate themselves along geomagnetic lines.

(iii) **Food Reserve**. Blue green algae have **cyanophycean starch** or α–granules, β-granules or **lipid globules** and **cyanophycin** or protein granules. In bacteria, starch is replaced by glycogen. Neutral fats are absent. Instead **poly-beta-hydroxy-butyrate** or PBH granules are present. A biodegradable plastic can be prepared from PBH. Protein granules are present. Carboxysomes occur in photosynthetic forms.

6. **Flagella** (Fig. 2.10). Bacterial flagella are unistranded, equivalent to a single microtubular fibre. It is about 20 nm (0.02 μm) in diameter and 1-7μm in length. Bacterial flagellum

is made up of 3 parts— **basal body, hook** and **filament**. Basal body is like a rod. It is inserted in the cell envelope. The basal body bears ring-like swellings in the region of plasma membrane and cell wall. There are two pairs of rings (L and P ring in cell wall and S and M rings embedded in cell membrane) in Gram negative bacteria and only a single pair of rings (S and M rings embedded in cell membrane) in Gram positive bacteria. Hook is curved tubular structure which connects the filament with the basal body. It is the thickest part of flagellum. Filament part is long tubular structure which causes turbulence in the liquid medium. It is made up of protein called **flagellin.** Protein molecules are globular. They are arranged in 3–11 spiral rows (Fig. 2.10 C). A proton pump or **stator** and a molecular motor or **rotator** occur at the bottom of basal body. The bacterial flagella perform rotation type movement (Lowy and Spencer 1968) that brings about backward pushing of the water. It results in the bacterium moving forward.

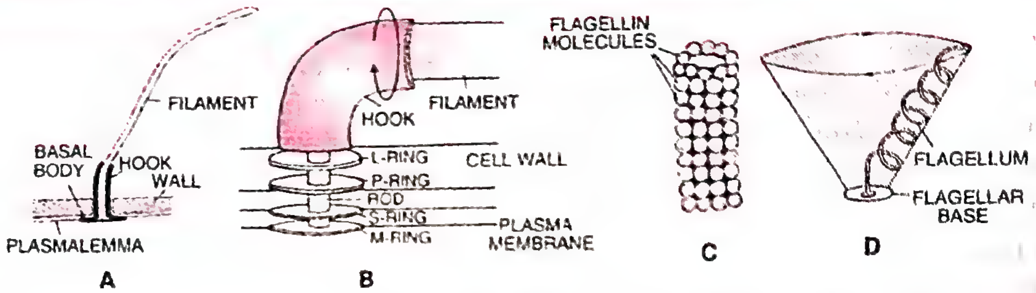


Fig. 2.10. Bacterial flagellum. A, parts of flagellum. B, Lower region of flagellum of a gram negative bacterium. C, filament canal with flagellin molecules. D, mode of flagellar movement.

Differences between Prokaryotic and Eukaryotic Flagella

Prokaryotic Flagella	*Eukaryotic Flagella*
1. They are single stranded.	1. They are 11-stranded.
2. A covering membranous sheath is absent.	2. Flagella are covered by sheath derived from plasmalemma.
3. The size is smaller.	3. The size is larger.
4. They are narrower.	4. They are thicker.
5. Each flagellum has three parts— basal body, hook and filament.	5. There are two parts, basal body and shaft.
6. Basal body bears rings.	6. Basal body bears rootlets.
7. They are formed of protein flagellin.	7. The strands are formed of protein tubulin.
8. They perform rotatory movements.	8. They perform lashing or undulatory movements.

7. **Pili and Fimbriae**. The two terms have been used interchangeably for bacterial appendages which are not involved in locomotion. Actually, pili (singular-pilus) are longer, fewer and thicker tubular outgrowths which develop in response to F^+ or fertility factor in Gram negative bacteria. They are made up of protein **pilin**. A donor bacterial cell having fertility factor develops 1–4 pili. Being long (18–20 μm) they are helpful in attaching to recipient cell and forming conjugation tube.

Fimbriae are small bristle-like protein fibres sprouting from cell surface in large number. There are 300–400 of them per cell. Diameter is 3–10 nm while length is 0.5–1.5 μm. Fimbriae are involved in attaching bacteria to solid surfaces (*e.g.*, rock in water body) or host tissues (*e.g.*, urinary tract in *Neisseria gonorrhoeae*). Some fimbriae cause agglutination of RBC. They also help in mutual clinging of bacteria.

Differences between Pili and Fimbriae	
Pili	*Fimbriae*
1. They occur only in Gram negative bacteria.	1. Fimbriae are found in both Gram +ve and Gram –ve bacteria.
2. The number is 1-4 per cell.	2. The number is 300-400 per cell.
3. Pili are longer and broader.	3. Fimbriae are shorter and narrow.
4. They help in conjugation.	4. They take part in adhesion.
5. Formation of pili is controlled by F^+ or fertility factor.	5. Formation of fimbriae is controlled by a nucleoid gene.
6. They are tubular structures.	6. They are bristle-like solid structures.

Plasmids (Gk. *plasma*– form)

They are small extrachromosomal rings of DNA present in monerans and some other organisms. Plasmids were discovered by Hayes and Lederberg (1952). They can replicate independent of nucleoid. Some plasmids can temporarily associate with the nucleoid. They are called **episomes** (Jacob and Wollmann, 1966). Today plasmids have become important tool in genetic engineering because they are used as vectors for introduction of genes. Plasmids can also pass from one bacterium to another. **They are, therefore, called transfer plasmids.** Plasmids carry **non-vital genes** which may or may not be useful to bacteria. Plasmids which do not confer any useful trait to the cells are called **cryptic plasmids**. Three types of useful plasmids are F-plasmids, R-plasmids and Col-plasmids.

F-Plasmids. They are plasmids which contain genes for conjugation or fertility. An F-plasmid is, therefore, also called **fertility factor** or **F-factor.** A bacterium having F-plasmid is called male or donor bacterium. It develops sex pili for conjugating with female or recipient bacterium which is devoid of F-factor. F-plasmid not only pass into recipient bacterium but can also help in transfer of nuclear genes from F^+ to F^- bacterium.

R-Plasmids. They are plasmids which carry genes for resistance against common antibiotics like chloramphenicol, tetracycline, streptomycin and sulphonamide. Pathogenic bacteria having R-plasmids are very difficult to treat.

Col-Plasmids. They are also called **colicinogenic factors.** They produce toxins called **colicins** or **bacteriocin** which are lethal to other enterobacteria. Col-plasmid can also get transferred from one bacterium to another just like F-plasmid or R-plasmid.

Reproduction

It occurs by three methods— binary fission, sporulation and sexual reproduction.

Binary Fission. It is the common method of bacterial multiplication under favourable conditions. A mature bacterium divides into two equal daughters. Binary fission of bacteria and other procaryotes does not involve the formation of a spindle. In this regard, it is similar to amitosis. In binary fission the nucleoid or bacterial chromosome replicates while attached to mesosome. A new mesosome develops and gets attached to the daughter chromosome. Membrane grows between the two mesosomes to push the daughter nuclear bodies or chromosomes to the opposite side. The cytoplasm now undergoes a transverse centripetal constriction in the middle to form two daughter protoplasts, each having a nuclear body. In the furrow between the two daughter protoplasts a double wall is deposited (Fig. 2.11). Ultimately both the daughter cells develop turgor and separate. Under favourable conditions, each daughter bacterium grows rapidly and becomes able to undergo binary fission after 20

minutes. This process, if continued, will produce after 24 hours about 4.7×10^{21} descendants of a single parent.

In binary fission the body of bacterium passes into its daughters before becoming old. Therefore, nothing dies and the bacteria are called **immortal**. However, death does occur due to change in environment, paucity of food and water, accumulation of waste products and development of bacteriophages.

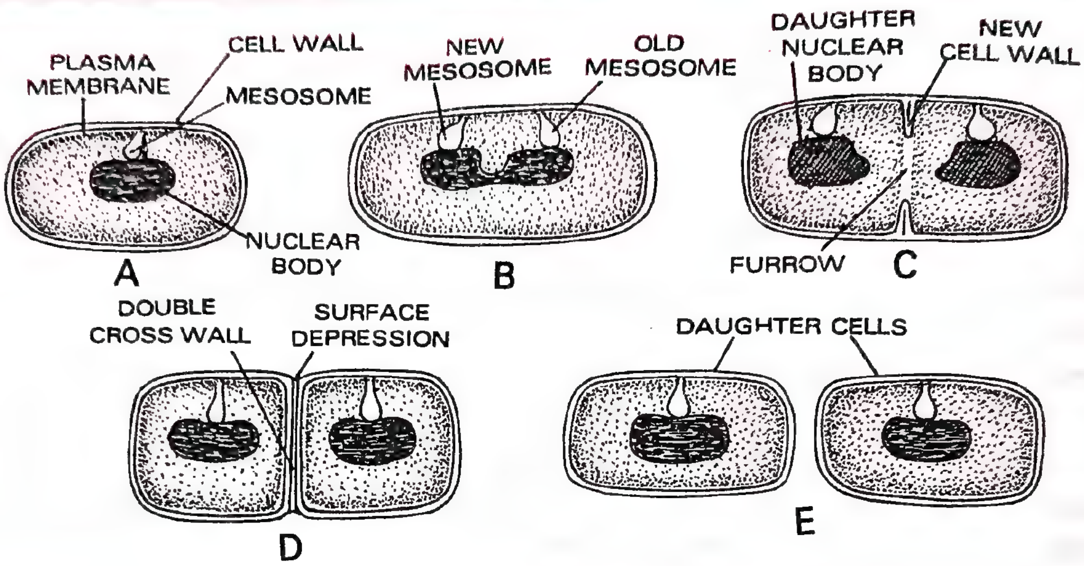


Fig. 2.11. Binary fission in a bacterial cell.

Sporulation

Bacteria produce several types of spores called gonidia, sporangiospores, arthrospores (oidia), conidia, cysts and endospores.

Endospores (Fig. 2.12). They are highly thick-walled and resistant spores which are formed in response to adverse environment, presence of harmful waste products or ageing

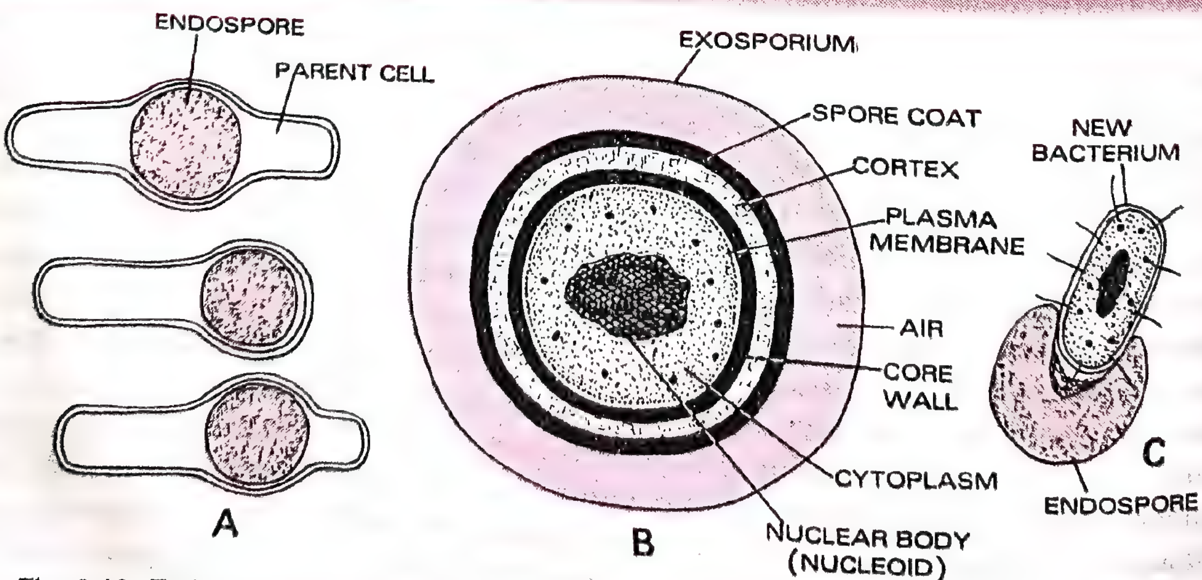


Fig. 2.12. Endospores. A, types of endospores according to their position in parent cells. B, structure of an endospore. C, germination of endospore.

of bacterial colony. A part of protoplast of the bacterial cell containing the nuclear body or nucleoid stores food, undergoes dehydration and separates from the rest by means of mesosome and ingrowth of plasma membrane. It is called **endospore primordium**. The primordium secretes a wall around it. More wall materials are deposited over it by the surrounding cytoplasm to form the endospore. The residual cytoplasm and wall of parent bacterium undergo autolysis. The liberated endospore is dispersed by air currents and on germination forms a new bacterium.

Endospores can easily tolerate a temperature of ± 100°C. Toxic chemicals have no effect on them. The resistant nature of endospores is due to their thick wall, low water content and the presence of an anticoagulant chemical known as dipicolinic acid. Fortunately, only two pathogenic bacteria *Clostridium tetani* and *Bacillus anthracis* produce endospores.

Sexual Reproduction (Parasexuality)

Typical sexual reproduction is absent in bacteria because of absence of meiosis and gamete formation. Instead, gene recombination occurs parasexually by three methods—conjugation, transformation and transduction.

Conjugation. It was first discovered in *Escherichia coli* by Lederberg and Tatum (1946). They found that two different types of auxotrophs (nutritional mutants) grown together on minimal medium produced an occasional prototroph (wild type). Cell contact was required for this change. Anderson (1957) observed conjugation between two such bacteria under electron microscope. Conjugation was later reported in a number of other bacteria. Bacteria showing conjugation are **dimorphic**, *i.e.*, they have two types of cells, **male** (F^+) or **donor** and **female** (F^-) or **recipient**. The male or donor cell possesses 1–4 sex pili on the surface and **fertility factor** (transfer factor, sex factor) in its plasmid. Fertility factor contains genes for producing sex-pili and other characters needed for gene transfer. Sex pili are 1– 4 narrow protoplasmic outgrowths. Both sex pili and fertility factor are absent in female or recipient cells. If these two types of cells happen to come nearer, a pilus of male cell establishes a protoplasmic bridge or conjugation tube with the female cell. It takes 6–8 minutes. Gene exchange can occur by two methods (Fig. 2.13).

(a) *Sterile Male Method* ($F^+ \times F^- \longrightarrow F^-$ becomes F^+). The plasmid having fertility factor replicates. A copy of it gets transferred to the recipient cell through the conjugation tube. The recipient cell also becomes donor. The phenomenon of reversibility of sex is called **sexduction**.

(b) *Fertile Male Method* (Hfr × $F^- \longrightarrow F^-$ remains F^-). The F^+ plasmid or fertility factor of the donor cell gets integrated to bacterial chromosome or DNA. The attachable plasmid is known as **episome**. The point at which plasmid gets integrated to bacterial chromosome differs in different strains. Integration is possible because certain nucleotide sequences present in bacterial chromosome are compatible with sequences in plasmid DNA. The donor cell having fertility factor integrated to its chromosome is called **Hfr** (high frequency of recombination), **meta male** or super male because it has a recombination frequency of 1000 times more as compared to normal F^+. Nonintegrated F^+ plasmids dis-integrate in Hfr cells. The integrated F^+ factor breaks the bacterial chromosome at one end of its attachment. The bacterial chromosome now undergoes replication. A copy of the freed end of bacterial chromosome (end distal to F^+ factor, also called zero end) passes into the recipient cell through the conjugation tube. Fertility factor is the last to do so. Generally whole of bacterial chromosome does not pass into recipient cell. F^+ factor is very rarely transferred as conjugation is maintained for a brief period. Only a few genes are transferred, one in seven minutes, two in nine minutes, three in ten minutes, four in eleven minutes, etc.

(Wollman and Jacob, 1966). Conjugation produces an incompletely diploid "zygote" known as **merozygote** or partial zygote. The new genes may replace the genes present in the recipient cells (those of the recipient cells disintegrate) or get added to them.

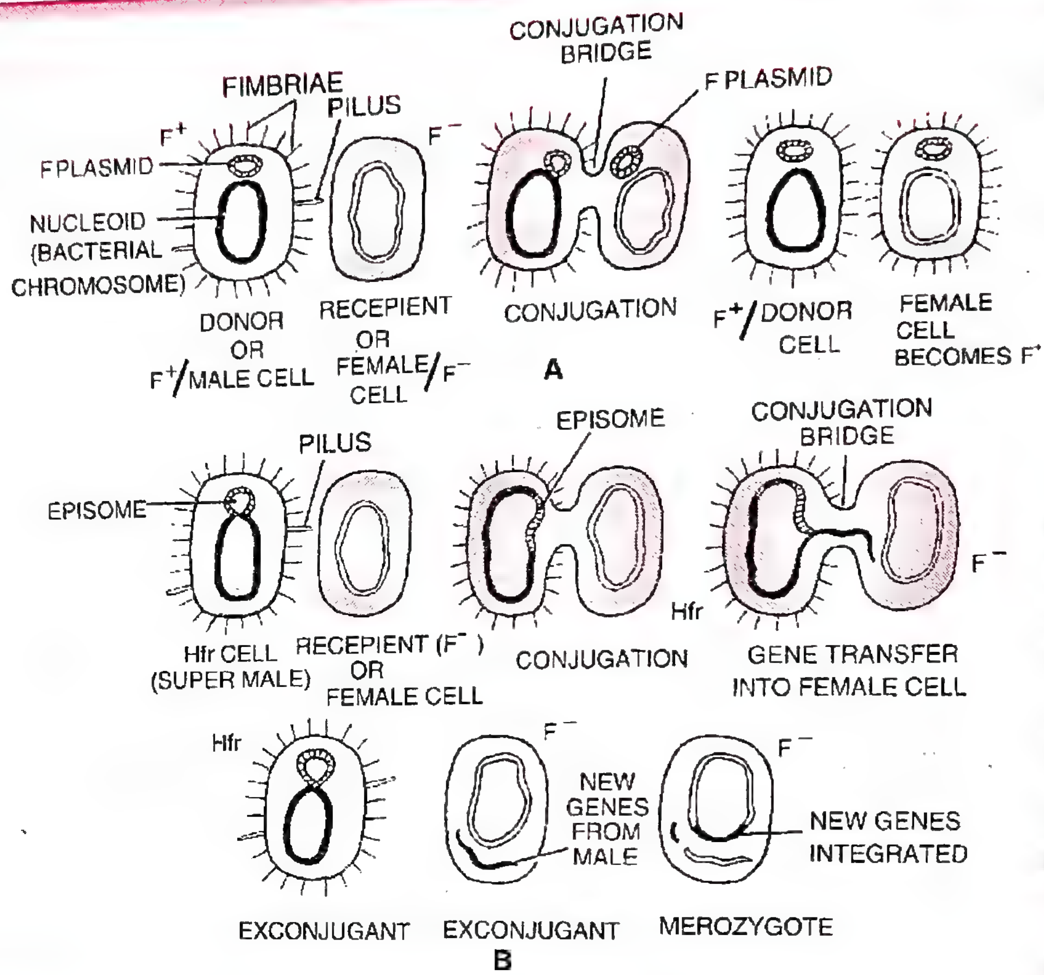


Fig. 2.13. Conjugation in Bacteria. A, Sexduction (Sterile male method). B, Transfer of chromosomal genes (Fertile male method).

Transformation. It is the absorption of DNA segment from the surrounding medium by a living bacterium. The phenomenon was discovered by Griffith in 1928. Its mechanism was worked out by Avery *et al* (1944). Receptivity for transformation is present for a brief period when the cells have reached the end period of active growth. At this time they develop specific receptor sites in the wall. Normally *E. coli* does not pick up foreign DNA but it can do so in the presence of calcium chloride.

Transduction (Fig. 2.14). It is the transfer of foreign genes by means of viruses. Transduction was first discovered by Zinder and his teacher Lederberg (1952) in *Salmonella typhimurium.* The process also occurs in *E. coli* and a number of other hosts. A virus may pick up gene of the host in place of its own gene during its multiplication in the host cell. Such a virus is never virulent. It passes over the gene of the previous host to the new host. Transducing viruses may carry the same genes (**restricted transduction**) or different genes (**generalised transduction**) at different times.

Respiration

According to the mode of respiration, bacteria can be aerobic or anaerobic. Each of them is further of two types, obligate and facultative.

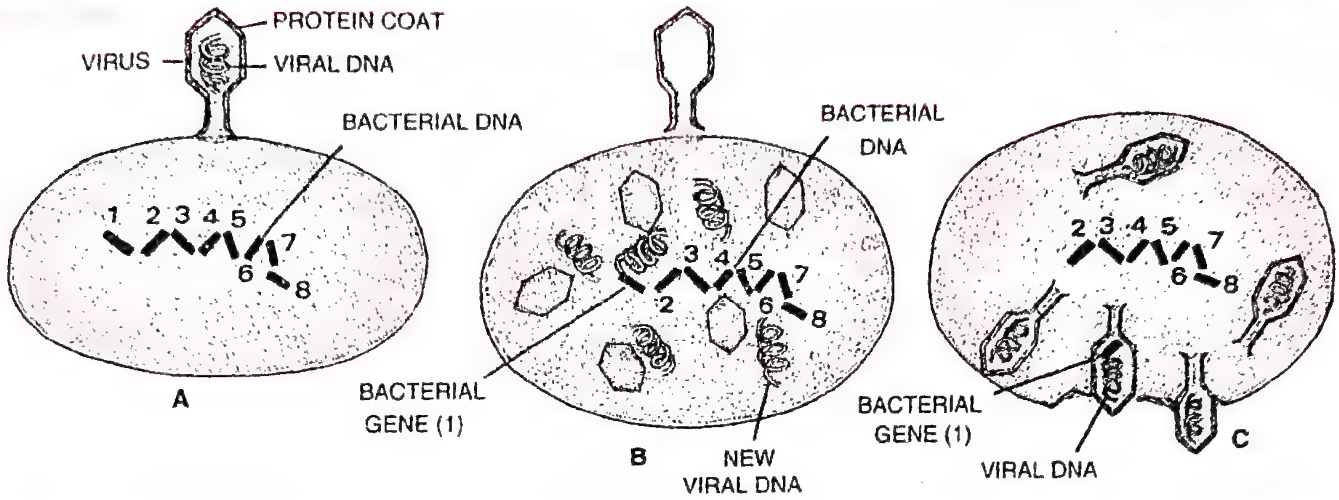


Fig. 2.14. Transduction in bacteria.

(a) *Obligate Aerobes*. They are bacteria which can respire only aerobically. They generally get killed under anaerobic conditions, *e.g., Bacillus subtilis*.

(b) *Facultative Anaerobes*. They are bacteria which generally respire aerobically but switch over to anaerobic mode of respiration if oxygen becomes deficient, *e.g.*, halophiles.

(c) *Obligate Anaerobes*. The bacteria of this category respire only anaerobically. They generally get killed under aerobic conditions, *e.g., Clostridium botulinum*.

(d) *Facultative Aerobes*. They are bacteria which respire anaerobically under normal conditions but can respire aerobically when oxygen is available. Most of the photosynthetic bacteria (*e.g., Rhodopseudomonas*) belong to this group.

Nutrition

Bacteria show both autotrophic and heterotrophic nutrition. Autotrophic nutrition consists of manufacture of organic materials from inorganic raw materials with the help of energy obtained from outside sources. It is of two types, chemosynthesis and photosynthesis. The bacteria performing these modes of nutrition are respectively called chemoautotrophs and photoautotrophs. Heterotrophic nutrition involves the obtaining of readymade organic nutrients from outside sources. It is of further three types— saprotrophic, symbiotic and parasitic.

1. **Photoautotrophic Bacteria**. The bacteria possess photosynthetic pigments of two types, **bacteriochlorophyll** and **bacteriophaeophytin** (chlorobium chlorophyll). The two types of pigments respectively occur in purple bacteria (*e.g., Thiopedia rosea, Rhodopseudomonas palustris*) and green sulphur bacteria (*e.g., Chlorobium limicola*). The pigments occur in the membranes of thylakoids. The photosynthetic bacteria are anaerobic. No oxygen is evolved in bacterial photosynthesis. Such type of photosynthesis is known as **anoxygenic photosynthesis**. Water is not used as a source of reducing power. Instead, hydrogen is obtained either directly (some purple bacteria) or from various types of inorganic and organic compounds, *e.g.*, H_2S (green bacteria), aliphatic compounds (purple nonsulphur bacteria).

$$\underset{\text{Hydrogen sulphide}}{H_2S} \longrightarrow 2[H] + S$$

$$\underset{\text{Sodium thiosulphate}}{Na_2S_2O_3 + 5H_2O} \longrightarrow 2NaHSO_4 + 8\ [H]$$

$$\underset{\text{Propyl alcohol}}{CH_3CHOH\ CH_3} \longrightarrow CH_3COCH_3 + 2\ [H]$$

Hydrogen from the above mentioned sources is picked up by NAD^+. In photochemical phase the photosynthetic pigments especially the bacteriochlorophyll synthesises ATP. The energy and the reducing power is used in the synthesis of organic compounds.

$$6CO_2 + 12H_2 \xrightarrow[\text{Enzymes}]{\text{Light Energy}} C_6H_{12}O_6 + 6H_2O$$

Because the photoautotrophic bacteria do not require oxygen, these monerans live comfortably near the bottoms of ponds and lakes where reduced sulphur and other compounds are freely available and the oxygen content is very low.

2. **Chemoautotrophic Bacteria.** They are bacteria which are able to manufacture their organic food from inorganic raw materials with the help of energy derived from exergonic chemical reactions involving oxidation of an inorganic substance present in the external medium. The chemical energy obtained from oxidation reaction is trapped in ATP molecules. This energy is then used in carbon assimilation with the help of hydrogen brought from sources other than water. There are several types of chemoautotrophic bacteria but the well known examples are nitrifying bacteria, sulphur oxidising bacteria, and iron bacteria.

(i) **Nitrifying Bacteria.** *Nitrosomonas* and *Nitrosococcus* obtain energy by oxidising ammonia to nitrite.

$$NH_4^+ + 2O_2 \longrightarrow NO_2^- + 2H_2O + \text{Energy}$$

Nitrocystis and *Nitrobacter* oxidise nitrites to nitrates.

$$2\ NO_2^- + O_2 \longrightarrow 2\ NO_3^- + \text{Energy}$$

(ii) **Sulphur Oxidising Bacteria.** *Beggiatoa*, a colourless sulphur bacterium, oxidises hydrogen sulphide to sulphur in order to obtain energy for chemosynthesis.

$$2H_2S + O_2 \xrightarrow{\textit{Beggiatoa}} 2S + 2H_2O + \text{Energy}$$

Thiobacillus thioxidans, another sulphur bacterium, oxidises sulphur to sulphate state.

$$2S + 2H_2O + 3O_2 \xrightarrow[\textit{thioxidans}]{\textit{Thiobacillus}} 2H_2SO_4 + \text{Energy}$$

(iii) **Iron Bacteria.** *Ferrobacillus ferro-oxidans* obtains energy by oxidising ferrous compounds to ferric forms.

$$4FeCO_3 + 6H_2O + O_2 \longrightarrow 4Fe(OH)_3 + 4CO_2 + \text{Energy}$$

(iv) **Other Chemosynthetic Bacteria.** Bacterium *Methanomonas* oxidises methane into CO_2 and H_2O.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{Energy}$$

Carbon monoxide bacterium, *Carboxydomonas*, oxidises carbon monoxide to carbon dioxide for obtaining energy.

$$2CO + O_2 \longrightarrow 2CO_2 + \text{Energy}$$

There are a number of hydrogen bacteria which oxidise hydrogen (*e.g., Thiothrix*) with the help of either oxygen or oxidised salts for getting energy required in chemosynthesis.

$$2H_2 + O_2 \longrightarrow 2H_2O + \text{Energy}$$
$$4H_2 + H_2SO_4 \longrightarrow H_2S + 4H_2O + \text{Energy}$$
$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O + \text{Energy.}$$

Differences between Chemosynthesis and Photosynthesis

Chemosynthesis	*Photosynthesis*
1. It does not require light as a source of energy.	1. Sunlight is essential for providing energy required for synthesis of food. Bacteria can, however, obtain some energy from infra-red rays.
2. Chemosynthesis can continue throughout day and night.	2. It occurs only during the day.
3. Photosynthetic pigments are absent.	3. Photosynthetic pigments are present. They are required for trapping radiation energy.
4. The energy required for synthesis of food is obtained by oxidising substances found in the surrounding medium.	4. There is no such activity.
5. The planet is not benefitted since there is no extra planetary source of energy.	5. There is a net gain of energy on our planet.
6. It is comparatively slower process.	6. Photosynthesis is comparatively rapid process.
7. Chemosynthesis occurs only in some bacteria.	7. Photosynthesis is found in bacteria, cyanobacteria, some protistans and plants.
8. It is always anoxygenic.	8. Bacterial photosynthesis is anoxygenic but photosynthesis of other organisms is oxygenic.

3. **Saprophytic Bacteria**. They are free living bacteria which obtain their food from organic remains, *e.g.*, corpses, animal excreta, fallen leaves, vegetables, fruits, meat, jams, jellies, bread and other products of plant and animal origin. Anaerobic breakdown of carbohydrates is often known as **fermentation**. Anaerobic breakdown of proteins is known as **putrefaction**. Aerobic breakdown of organic compounds is known as **decay**.

Saprophytic bacteria are both useful and harmful to human interests. The harmful activities include spoilage of food stuffs, food poisoning, denitrification of soils, desulphurification of soils and deterioration of a number of household articles like fibres, leather and wooden articles.

Saprophytic bacteria have been employed in several economically useful activities. In nature they alongwith fungi, are the **decomposers** of organic remains. This activity not only disposes off the dead bodies and organic wastes but also releases raw materials for reutilization. Therefore, saprophytic bacteria are called **nature's scavengers**. Saprophytic bacteria take part in disposal of sewage, production of manure, ensilage, preparation of curd and cheese, retting of fibres, cleaning of hides, curing of tea, tobacco, coffee and cocoa, industrial synthesis of alcohols and organic acids, vitamins, enzymes, antibiotics, etc. The latest use of this type of bacteria is in the biodegradation of organic pollutants like petroleum spillage, *e.g., Pseudomonas.*

4. **Symbiotic Bacteria**. These bacteria live in mutually beneficial association with other

organisms. Enteric bacterium *Escherichia coli*, lives as a commensal in human intestine. It feeds on undigested matter, checks the growth of putrefying bacteria and produces large quantities of several B vitamins as well as vitamin *K*. Another common symbiotic bacterium is *Rhizobium*. It has several species which form association with nodulated roots of different legumes. The bacterium obtains shelter and food from the legume. It performs nitrogen fixation inside the nodules (not in the free state). There are several other examples of nitrogen fixing symbiotic bacteria, *e.g., Frankia, Xanthomonas*.

5. **Parasitic Bacteria**. The bacteria live in contact with other living beings for obtaining nourishment or special organic compounds required for growth (growth factors). Parasitic bacteria may or may not cause disease. Disease producing forms are called **pathogenic bacteria**. The disease is produced either due to breakdown of the host cells or due to liberation of **toxins**. Toxins are further of two types, **endotoxins** (*e.g., Vibrio cholerae*—vibrio bacteria) and **exotoxins** (*e.g., Clostridium tetani*—bacillus bacteria). Pathogenic bacteria produce 90% of the human diseases. In plants the bacterial diseases rank second to fungal diseases. Two common bacterial diseases of plants are crown galls (*Agrobacterium tumefaciens*) and Citrus canker (*Xanthomonas citri*). Some examples of human diseases caused by bacteria are :

1. Tuberculosis— *Mycobacterium tuberculosis*	(Simple Actinomycetes)
2. Leprosy— *Mycobacterium leprae*	(" ")
3. Bubonic Plague— *Pasteurella pestis*	(Bacillus Bacteria)
4. Tetanus (Lock Jaw)— *Clostridium tetani*	(" ")
5. Bacterial influenza— *Haemophilus influenzae*	(" ")
6. Whooping cough— *Haemophilus* or *Bordetella pertusis*	(Bacillus Bacteria)
7. Cholera— *Vibrio cholerae*	(Vibrio bacteria)
8. Syphilis— *Treponema pallidum*	(Spirochaete)
9. Gonorrhoea— *Neisseria gonorrhoeae*	(")
10. Diphtheria— *Corynebacterium diphtheriae*	(Simple Actinomycetes)
11. Pneumonia— *Diplococcus pneumoniae*	(Coccus)
12. Typhoid— *Salmonella typhi* (= *S. typhosa*)	(Bacillus Bacteria)

Antibiotics

They are substances produced by micro-organisms which in low concentration are antagonistic to the growth of other micro-organisms (Waksman, 1942). Medicinally antibiotics are those organic secretions which destroy or check the growth of different pathogens without harming the host. The first commercial antibiotic was Penicillin discovered by Fleming (1929) from a fungus called *Penicillium*. The first antibiotic was, however, extracted a few years earlier by Gratia and Tash (1924) from a mycelial bacterium. Maximum number of antibiotics are produced by mycelial bacteria known as actinomycetes. Some of the important antibiotics are as follows :

1. Streptomycin— *Streptomyces griseus*
2. Chloromycetin or chloramphenicol— *Streptomyces venezuelae* and *S. lavendulae*
3. Tetracyclines— *Streptomyces aureofaciens*
4. Terramycin— *Streptomyces ramosus*
5. Erythromycin— *Streptomyces erythreus* (= *S. erytheraeus*)
6. Bacitracin— *Bacillus licheniformis*

Economic Importance of Bacteria

1. Harmful activities

(i) **Spoilage of Food**. Saprotrophic bacteria cause rotting of vegetables, fruits, meat, bread, souring of milk, cheese, butter and spoilage of jams, jellies and pickles.

(ii) **Food Poisoning**. Botulism is caused by an anaerobic bacterium *Clostridium botulinum* (= *C. perfringens*). The bacterium infects canned food. Common food poisoning is caused by *Staphylococcus aureus*. The poisoning is accompanied by diarrhoea and vomiting. Another is salmonellosis which is generally produced on eating contaminated meat. Bacterium causing this type of poisoning is *Salmonella enteridis* and *S. typhimurium*.

(iii) **Deterioration of Domestic Articles**. *Spirochaete cytophaga* deteriorates cotton fibres, leather and wooden articles.

(iv) **Destruction of Penicillin**. *Bacillus brevis* destroys penicillin.

(v) **Denitrification of Soils**. *Thiobacillus denitrificans* and *Micrococcus denitrificans* convert nitrates of the soil into gaseous nitrogen.

(vi) **Desulphurification of Soils**. *Desulfovibrio desulfuricans* changes soil sulphates into H_2S.

(vii) **Diseases**. Over 90% of human and animal diseases are caused by bacteria and over 40% of plant diseases are due to them.

2. Beneficial Activities

Role in Agriculture

(i) **Nature's Scavengers**. Alongwith saprotrophic fungi, saprotrophic bacteria cause decay and decomposition of dead bodies of plants and animals. In the process they cleanse the earth and release raw materials for new generations.

(ii) **Sewage Disposal**. Organic content of sewage is broken down by the bacteria.

(iii) **Ammonifying Bacteria**. *Bacillus vulgaris* releases ammonia from amino acids.

(iv) **Nitrifying Bacteria**. *Nitrosomonas* and *Nitrosococcus* oxidise ammonium salts to nitrites. The nitrites are further changed into nitrates by *Nitrobacter* and *Nitrocystis*.

(v) **Nitrogen Fixing Bacteria**. A few free living bacteria are able to pick up dinitrogen from the soil atmosphere and convert it into organic nitrogenous materials like amino acids, *e.g., Azotobacter, Beijerinckia, Clostridium pasteurianum.*

Symbiotic nitrogen fixing bacteria of the genus *Rhizobium* occur in the root nodules of a number of legumes (Fig. 2.15). These legumes are used in crop rotation and green manuring. The plants as well as their seeds are rich in proteins. Root nodules containing symbiotic nitrogen bacteria also occur in *Casuarina* and *Alnus*. Leaf nodules containing such bacteria are found in *Ardisia*.

(vi) **Manure**. The saprotrophic bacteria convert farm refuse, dung and other organic wastes into manure.

(vii) **Gobar Gas Plants**. They employ bacteria for converting animal dung and other organic wastes into manure along with production of fuel gas.

(viii) **Sulphur Bacteria**. *Beggiatoa* and other sulphur bacteria pick up H_2S released during putrefaction of proteins to produce sulphates.

(ix) **Ensilage**. Ensilage is preserved cattle feed or fodder. It is formed by packing fresh chopped fodder in silos sprinkled with molasses. Fermentation activity of bacteria produces lactic acid which has a preservative action.

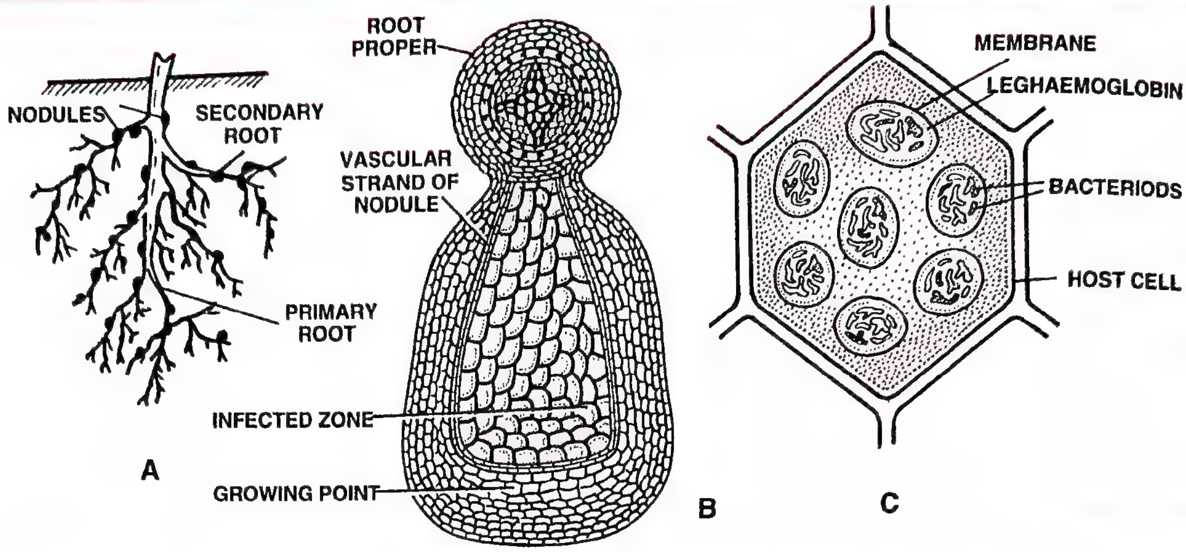


Fig. 2.15. Symbiotic nitrogen fixation. A, nodulated roots of a legume. B, T.S. root nodule. C, nodule cell with bacterioids of *Rhizobium.*

Role in Industry

(x) **Dairy Industry**. Lactic acid bacteria (*e.g., Streptococcus lactis*) convert milk sugar lactose into lactic acid.

$$\underset{\text{Lactose}}{C_{12}H_{22}O_{11}} + H_2O \longrightarrow \underset{\text{Lactic Acid}}{4\ C_3H_6O_3} + \text{Energy}$$

Lactic acid coagulates milk protein casein and converts milk into yoghurt, curd and cheese.

(xi) **Lactic Acid**. Lactic acid is commercially got from ammoniated sugar solution through fermentation caused by *Lactobacillus delbreuckii*. Acid is used in food preservation, tanning and preparation of a number of drugs.

(xii) **Vinegar**. Acetic acid bacteria (*Acetobacter aceti*) oxidise ethyl alcohol into acetic acid. Ethyl alcohol is got from molasses.

(xiii) **Butyl Alcohol and Acetone**. *Clostridium acetabutylicum* is able to produce butyl alcohol, methyl alcohol and acetone from molasses.

(xiv) **Retting of Fibres**. Stem and leaf fibres are separated from softer tissues by bacterial action of two types— dew retting (*e.g., Pseudomonas fluorescence*) and anaerobic retting (*e.g., Clostridium* or butyric acid bacteria).

(xv) **Curing**. Leaves of tea and tobacco are cured off their bitterness with the help of certain bacteria, *e.g., Bacillus megatherium*. Beans of coffee and cocoa are similarly cured.

(xvi) **Cleaning of Hides**. Hides are cleaned of their fat, hair and other attached tissues by bacterial action. Commercial sponges are cleaned similarly.

(xvii) Several bacteria synthesise cellulose which can be put to several uses, *e.g., Acetobacter, Azotobacter.*

(xviii) **Antibiotics**. A number of antibiotics are obtained from mycelial bacterium *Streptomyces* (*e.g.,* Streptomycin, Chloramphenicol, Tetracycline, Oxytetracycline). A number of antifungal medicines are also produced by this genus, *e.g.*, hamycin, trichomycin, primaricin. Bacitracin, subtilin, polymyxin, gramicidin are some other antibiotics obtained from bacteria.

(xix) **Vitamins**. Riboflavin was formally prepared from *Clostridium butylicum*. Cobalamine (B_{12}) is obtained from bacteria like *Bacillus megatherium*. Acetic acid bacteria are used in some steps during the preparation of vitamin C. *Escherichia coli* present in the human intestine produces large quantities of vitamin *K* and *B* complex vitamins.

ARCHAEBACTERIA

They are a group of most primitive procaryotes which are believed to have evolved immediately after the evolution of the first life. They have been placed in a separate subkingdom or domain of Archaea by a number of workers (*e.g.*, Woese, 1994). Archaebacteria are characterised by absence of peptidoglycan in their wall. Instead the wall contains protein and noncellulosic polysaccharides. It has **pseudomurein** in some methanogens. The cell membranes are characterised by the presence of a monolayer of branched chain lipids. Their 16S rRNA nucleotides are quite different from those of other organisms. Core histones are present. DNA replication, transcription and translation are quite similar to those of eukaryotes. Operons are monocistronic.

Many archaebacteria even now live under extremely hostile conditions where very few other organisms can dare subsist, *e.g.*, salt pans, salt marshes, hot sulphur springs seawents. The archaebacteria are of two broad categories, obligate anaerobes and facultative anaerobes. Obligate anaerobes can live under anaerobic conditions only. They get killed in the presence of oxygen, *e.g.*, methanogens. Facultative anaerobes are actually aerobic archaebacteria which can bear anaerobic conditions comfortably. They are represented by thermoacidophiles and halophiles.

Archaebacteria are of three major types— methanogenes, halophilic and thermoacedophilic. Methanogens and halophiles are placed in division euryarchaeota while thermoacidophiles are placed in division creuarchaeota.

Methanogens. The archaebacteria are strict **anaerobes**. Nutritionally they are "autotrophs" which obtain both energy and carbon from decomposition products. They occur in marshy areas where they convert formic acid and carbon dioxide into methane with the help of hydrogen. This capability is commercially exploited in the production of methane and fuel gas inside gobar gas plants *e.g.*, *Methanobacterium, Methanococcus*. Some of the methanogen archaebacteria live as symbionts (*e.g.*, *Methanobacterium*) inside rumen or first chamber in the stomach of herbivorous animals that chew their cud (ruminants, *e.g.*, cow, buffalo). These archaebacteria are helpful to the ruminants in fermentation of cellulose.

Halophiles (Halophils). Halophiles are named so because they usually occur in salt rich substrata (2.5–5.0 M) like salt pans, salt beds and salt marshes *e.g.*, *Halobacterium, Halococcus*. They are aerobic chemoheterotrophs. Their cell membranes have red carotenoid pigment for protection against harmful solar radiations. Under anaerobic conditions, halophiles cannot use external materials. At this time they subsist on ATP synthesised by membrane pigment system from solar radiations.

Halophiles are able to live under high salt conditions due to four reasons— (1) Presence of special lipids in the cell membranes. (2) Occurrence of mucilage covering. (3) Absence of sap vacuoles and hence plasmolysis. (4) High internal salt content. Halophiles growing in salt pans and salt beds give offensive smell and undesirable pigmentation to the salt.

Thermoacidophiles (Thermoacidophils). These archaebacteria have dual ability to tolerate high temperature as well as high acidity. They often live in **geothermal vents** as well as hot sulphur springs where the temperature may be as high as 80°C and *p*H as low as 2, *e.g.*, *Thermoplasma, Thermoproteus*. Basically these archaebacteria are chemosynthetic, *i.e.*, they obtain energy for synthesis of food from oxidising sulphur. Under aerobic conditions they usually oxidise sulphur to sulphuric acid.

$$2S + 2H_2O + 3O_2 \longrightarrow 2H_2SO_4$$

If the conditions are anaerobic, the thermoacidophiles may reduce sulphur to H_2S. Bicarbonates are also precipitated into the carbonate form by their activity.

Thermoacidophiles are able to tolerate high temperature as well as high acidity due to two reasons : (1) Branched chain lipids in the cell membranes. (2) Presence of special resistant enzymes capable of operating under acidic conditions.

Archaebacteria are also known as **ancient living fossils** because they represent one of the earliest forms of life which experimented on the absorption of solar radiations for the first time, lived comfortably under anaerobic conditions and developed techniques to oxidise the chemicals present in the substratum on the availability of oxygen.

Uses. (i) Archaebacteria are employed in the production of gobar gas from dung and sewage. (ii) In ruminants, they cause fermentation of cellulose.

MYCOPLASMA (PPLO)

Mycoplasmas or **mollicutes** are the simplest and the smallest of the free living procaryotes. They were discovered in pleural fluid of cattle suffering from pleuropneumonia (Nocard and Roux, 1898). The organisms are often called MLOs (Mycoplasma like organisms) or PPLOs (Pleuropneumonia like organisms). The size ranges from 0.1–0.15 μm. A cell wall is absent. Plasma membrane forms the outer boundary of the cell. Due to the absence of cell wall the organisms can change their shape and are **pleomorphic**. Like other procaryotes, mycoplasmas possess one envelope system. They lack organised nucleus, endoplasmic reticulum, plastids, mitochondria, golgi bodies, lysosomes, centrioles, flagella, etc. The genetic material is represented by a single DNA duplex which is naked because of absence of histone association. The DNA duplex is not compacted as in other procaryotes but instead lies coiled throughout the cytoplasm. Ribosomes are 70S. Enzymes lie both freely in the cytoplasm as well as associated with the plasma membrane. DNA possesses a **replicating disc** at one end to assist in replication and separation of the genetic material. Granules of various types occur here and there in the cytoplasm.

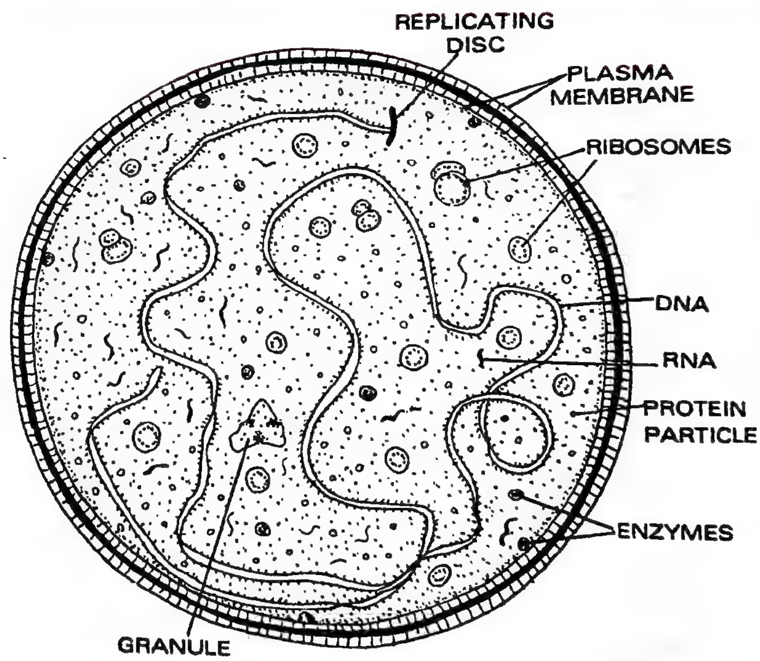


Fig. 2.16. Ultrastructure of PPLO.

Mycoplasmas are heterotrophic in their nutrition. Some of them live as saprophytes but majority parasitise plants and animals. The parasitic habit is due to the inability of most mycoplasmas to synthesise the required growth factors, *e.g., Mycoplasma gallisepticum, M. laidlawii*. They mostly produce pleuropneumonia in domestic animals, atypical pneumonia and mycoplasmal urethritis in humans, little leaf disease of Brinjal and witches broom in plants.

CYANOBACTERIA

(Blue Green Algae, Cyanophyceae, Myxophyceae)

Cyanobacteria or blue-green algae are Gram (+) photosynthetic procaryotes which perform **oxygenic photosynthesis**. Photosynthetic pigments include chlorophyll *a*, carotenoids and phycobilins. Food is stored in the form of cyanophycean starch, lipid globules and protein granules. Cyanobacteria evolved more than 3 billion years back. They added oxygen to the atmosphere and paved the path for evolution of aerobic forms, including aerobic bacteria.

Occurrence. Cyanobacteria or blue green algae are the one of most successful autotrophic organisms on earth which have mastered all types of environments— fresh water, sea water, salt marshes, moist rocks, tree trunks, moist soils, hot springs, frozen waters. Their abundance can be gauged from the fact that **red sea** is named after the colouration provided by red coloured planktonic cyanobacteria known as *Trichodesmium erythraeum.*

Cyanobacteria are the most self contained photosynthetic organisms. They can, therefore, live under every type of environment and on every type of substrate. Because of this fact, they are one of the earliest colonizers of barren areas. Many of them have the ability of nitrogen fixation.

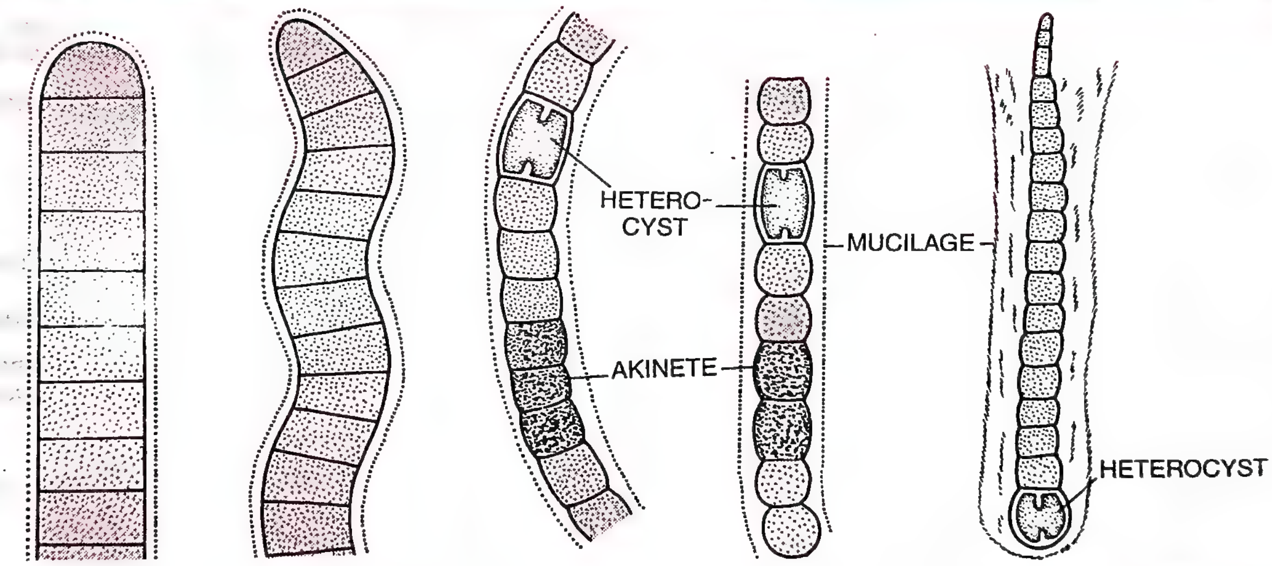


Fig. 2.17. Some common filamentous blue-green algae.

Morphology. Cyanobacteria may be unicellular, colonial or filamentous. Each filament consists of a sheath of mucilage and one or more cellular strands called **trichomes**. Single trichome filaments may further be of two types, homocystous (= undifferentiated, *e.g.*, *Oscillatoria*) and heterocystous (= differentiated, having heterocysts, *e.g.*, *Nostoc*). *Spirulina* has a spirally coiled filament. Colonies develop in some cases, *e.g.*, *Nostoc*.

Flagella are absent but gliding movements are known in a number of cyanobacteria. The name *Oscillatoria* has been given to a common blue green alga on the basis of pendulum like oscillating movements of its anterior region.

Cell Structure (Fig. 2.18). Cyanobacterial cells are larger and more elaborate than bacteria. Cell structure is typically procaryotic— one envelope organisation with peptidoglycan wall, naked DNA, 70S ribosomes and absence of membrane bound structures like

endoplasmic reticulum, mitochondria, golgi bodies, plastids, lysosomes, sap vacuoles. The cell wall is four layered with peptidoglycan present in the second layer. The outer part of the protoplast contains a number of photosynthetic thylakoids or chromatophores. It is called **chromoplasm**. The thylakoids lie freely in the cytoplasm. Their membranes contain chlorophyll *a*, carotenes and xanthophylls. Chlorophyll *b* is absent. Attached to the thylakoid membranes are small granules known as **phycobilisomes**. The latter possess accessory photosynthetic pigments known as phycobilins. The phycobilins are of three types— c-phycocyanin (blue), allophycocyanin (blue) and c-phycoerythrin (red). Differential formation of phycobilins produces specific colouration which is adapted for absorbing maximum amount of solar radiation. Therefore, cyanobacteria are not always blue green. They may appear purplish, violet, brownish, etc.

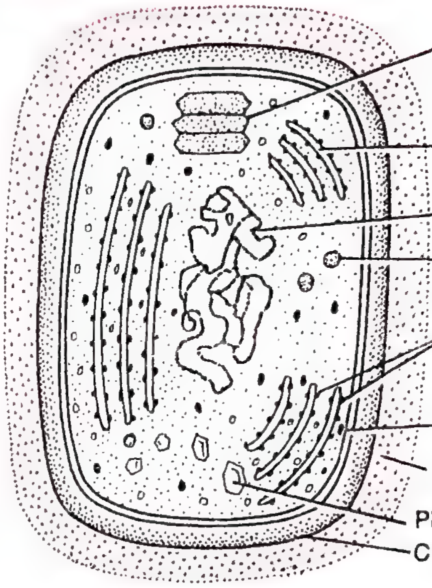


Fig. 2.18. Ultrastructure of a cyanophycean cell.

Instead of typical vacuoles or sap vacuoles, **gas vacuoles** or pseudo-vacuoles are found. Each gas vacuole consists of a number of submicroscopic units called **gas vesicles.** Gas vacuoles function as light screen, provide buoyancy regulating mechanism and pneumatic strength.

A naked, circular, double stranded DNA lies coiled generally in the central part of the cytoplasm known as **centroplasm**. The coiled up DNA is equivalent to a single chromosome of higher organisms. It is often called **nucleoid**. Like bacteria, small circular DNA segments may also occur in addition to nucleoid. They are known as plasmids or transposons. 70S ribosomes occur here and there. Semicircular group of coiled membranes often attaches the plasma membrane with the nucleoid. It is known as **lamellasome**. Four types of inclusions occur in the cells. They are α-granules (cyanophycean starch), β-granules (lipid droplets), volutin granules and polyhedral bodies (ribulose biphosphate carboxylase).

Heterocyst. It is a large-sized, pale coloured, thick-walled cell which occurs in terminal, intercalary or lateral position in filamentous cyanobacteria, *e.g., Nostoc*. The thick wall is impermeable to oxygen but permeable to nitrogen. Mucilage sheath is absent. Photosystem II is absent. Thylakoids lack phycobilisomes. Therefore, photosynthesis is absent but cyclic photophosphorylation occurs. Heterocyst is dependent for its nourishment on adjacent vegetative cells. It has enzyme nitrogenase. Heterocyst is specialised to perform nitrogen fixation.

Reproduction. Cyanobacteria mostly multiply by asexual methods. The latter include binary fission, fragmentation with or without formation of small segments called hormogones (hormogonia), hormospores, akinetes, endospores, nannocytes, exospores, etc. Typical sexual reproduction involving formation and fusion of gametes is absent but like bacteria gene recombination can occur by three types of parasexual methods (Kumar, 1985)— conjugation, transformation and transduction.

Importance. 1. They are one of the early colonizers of bare and barren areas. They provide suitable conditions for the growth of other organisms even in the most hostile environment.

2. Blue green algae function as food to several aquatic animals. *Spirulina* is regularly collected for human consumption in parts of Africa. *Nostoc* is similarly used in China. In Rajasthan, *Anabaena* and *Spirulina* are collected from Sambar lake and used as fodder and manure. *Spirulina* is very easily cultivated in tanks and can be used as a palatable protein rich food supplement for humans and animals.

3. Several cyanobacteria have the ability of nitrogen fixation. The filamentous forms possess special large pale cells or **heterocysts** for this (Fig. 2.19). Some of the fixed nitrogen comes out as excretion. After death of cyanobacteria the substratum becomes rich in nitrogen. Such nitrogen fixing cyanobacteria are now regularly inoculated in the rice fields. This saves consumption of nitrogen fertilizers.

4. Nitrogen fixing cyanobacteria are often used for reclaiming usar soils, *e.g., Nostoc, Anabaena*. These cyanobacteria produce acidic chemicals for counteracting alkalinity of the soil and nitrogenous compounds which are generally deficient in these soils.

5. Antibiotic can be manufactured from extract of *Lyngbia*.

6. Species of *Anabaena* and *Aulosira* do not allow mosquito larvae to grow nearby. Such cyanobacteria can be inoculated in village ponds and rice fields to prevent the growth of mosquitoes.

7. Cyanobacteria can grow on the walls and roofs of buildings during the rainy seasons causing discolouration, corrosion and leakage.

8. They produce water blooms, imparting bad odour and colour to water bodies.

9. Some cyanobacteria produce toxins harmful to most aquatic animals. They may prove equally toxic to human beings drinking or bathing in such water. The important toxins producing cyanobacteria are *Microcystis aeruginosa* (= *Anacystis cyanea*), *Anabaena flos-aquae, Aphanizomenon flos-aquae*.

Differences Between Bacteria and Cyanobacteria

Bacteria	*Cyanobacteria*
1. The cells are comparatively smaller.	1. The cells are comparativey larger.
2. The cell wall is 1—2 layered.	2. The cell wall is four layered.
3. Plasmodesmata and pores do not occur in cell walls.	3. They are often present.
4. They exhibit lesser structural elaboration.	4. They show higher degree of morphological complexity as well as structural elaboration.
5. Bacteria are both autotrophic and heterotrophic.	5. Cyanobacteria are generally autotrophic.
6. Autotrophic bacteria possess bacteriochlorophyll.	6. Cyanobacteria contain chlorophyll *a* as found in eucaryotic autotrophs.
7. Photosynthesis is anoxygenic.	7. Photosynthesis is oxygenic.
8. Photoautotrophic bacteria do not contain phycobilins.	8. They possess accessory water soluble photosynthetic pigments known as phycobilins.
9. Flagella may be present.	9. Filagella are absent.
10. Carbohydrate reserve food is glycogen.	10. Carbohydrate reserve food is a special starch known as cyanophycean starch.

Some common cyanobacteria :—

Spirulina. It is a spirally coiled, free floating, filamentous blue green alga or cyanobacterium

of upto 0.5 mm length. The trichomes appear to be unicellular but staining and electron microscopy has shown the presence of thin transverse walls (Holmren *et al*, 1971). The ends are rounded. It is also being cultured. It can grow both autotrophically and heterotrophically. Trichomes show rotary and bending movements.

This cyanobacterium is rich in protein (55% to 68%). It also contains minerals, vitamins (including B_{12}) and essential fatty acids. Because of its beneficial nature, *Spirulina* is used as food additive in the form of powder, pill or tablet. WHO has called it as greatest superfood. It is being produced on mass scale by NBRI Lucknow and CFTRI Mysore. *Spirulina* is also a good food supplement for animal feed. However, it should not form more than 10% of their diet (Beker and Venkataraman, 1984). The cyanobacterium is also used as manure. It is helpful in reclamation of usar soils. It has antiviral and anticancer properties, strengthening immune system of the body.

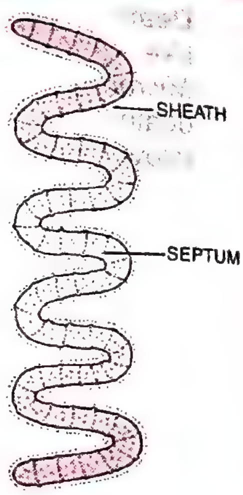


Fig. 2.19. *Spirulina*.

Nostoc. It is a colonial cyanobacterium that is popularly called **moonspit, fallen star** or **star jelly**. *Nostoc* occurs in both aquatic and subaerial habitats. It also forms symbiotic association with *Anthoceros*, Cycad roots, *Gunnera* stems and *Trifolium* roots. A colony contains a number of flexuous intertwined filaments on the periphery, a mucilage filled hollow interior and a dense mucilage covering on the outside. Each trichome is **beaded, S-shaped** and consists of a large number of vegetative cells, a few terminal and intercalary large pale coloured **heterocysts** and thick-walled resting cells called **akinetes**. Heterocysts are specialised to perform nitrogen fixation. Reproduction occurs through fragmentation, hormo-gones, akinetes and occasionally by heterocysts. Larger colonies of *Nostoc* are eaten in China and nearby areas. Because of its ability of nitrogen fixation, Nostoc enriches its habitat with nitrogen. It is also used in reclaming barren land and usar soil.

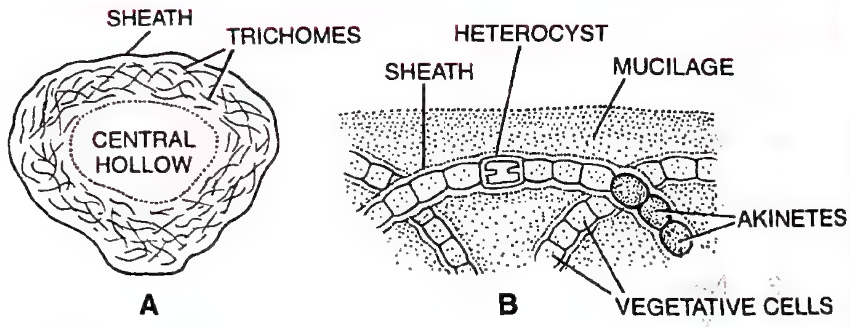


Fig. 2.20. *Nostoc*. A, Colony (external view). B, Colony (diagrammatic section). C, Part of colony showing trichomes.

ADDITIONAL INFORMATION

- **Hensen** (1874). Discovered *Mycobacterium leprae*, the leprosy causing bacterium. Leprosy is also called Hensen's disease.
- **Pasteurisation**. The technique of sterilisation of liquids was developed by Pasteur (1864).
- **Beijerinck** (1888). Found *Rhizobium* to take part in nitrogen fixation in root nodules of legumes.
- **Gastric or Peptic Ulcers.** Mostly due to bacterium *Helicobacter pylori.*
- **Bdellovibrio**. Highly motile small sized monotrichous bacteria that attack other bacteria, multiply inside their bodies and cause lysis of host cells. *Bdellovibrio bacteriovorous* is believed to help maintain **purity of Ganges.**

- **Plasmid Size.** It varies from 50–4000 Kb.
- **Death Factors.** Toxins from cyanobacteria like *Aphanizomenon*, *Anabaena* and *Microcystis*. Three types— VFDF (very fast death factor), FDF (fast death factor) and SDF (slow death factor).
- **Bioremediation.** Use of microorganisms for degradation of environmental pollutants.
- **Bioleaching.** Use of bacteria and other microorganisms for exploitation of poor mines through the process of solubilisation and leaching, *e.g.*, *Thiobacillus thioxidans.*

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. State two economically important uses of (a) Heterotrophic bacteria, (b) Archaebacteria.
   ✓ (a) These are used in agriculture (nitrogen fixation by *Rhizobium*; formation of manure and gobar gas), and industry (for producing curd, cheese, curing of tea leaves, retting of fibres, vinegar antibiotics vitamins).
   (b) These are used in gobar gas production and bioleaching of poor mines.
2. What does the algal bloom mean ?
   ✓ Algal bloom is exceptionally rich growth of algae, particularly of Cyanobacteria (blue green algae) over the surface of water bodies rich in nutrients. Algal bloom releases neurotoxins, deplete oxygen and make water unfit for use.

TEST QUESTIONS

One Mark Questions (With Answers)

1. What is progenote ?
   ✓ It includes the most primitive forms of life from which developed the prokaryotes.
2. Name a moneran which shows pendulum like movements.
   ✓ *Oscillatoria*
3. Name the two types of Eubacteria ?
   ✓ Bacteria and Cyanobacteria
4. Write the smallest and largest sizes of bacteria ?
   ✓ Smallest size is 0.15 µm while largest size is 500 µm.
5. Why cytoplasm of bacterial cell looks granular ?
   ✓ It is granular because of the dispersion of ribosomes throughout its length and breadth.
6. Name the bacterial photosynthetic pigments ?
   ✓ Instead of chlorophyll, the photoautotrophic bacteria contain bacteriochlorophyll or bacteriophaeophytin.
7. Bacteria show anoxygenic photosynthesis. Why ?
   ✓ Water is not used as a source of reducing power.
8. Which bacterium in human intestine produces large quantities of vitamin K and B ?
   ✓ *Escherichia coli*

Two Mark Questions (With Sample Answers)

1. What is the flagellar structure in bacteria ? Explain the grouping of bacteria on the basis of absence or presence of flagella ?
2. How bacteria are useful in industry ? Write any two uses ?
   ✓ **Vinegar.** Acetic acid bacteria (*Acetobacter aceti)* oxidise ethyl alcohol into acetic acid. Ethyl alcohol is got from molasses.
   Cleaning of Hides. Hides are cleaned of their fat, hair and other attached tissues by bacterial action.
   Commercial sponges are cleaned similarly.

3. Give suitable examples of the following :
   (a) Rod-shaped bacteria (b) Pigments of cyanobacteria (c) Nitrogen fixing monerans.
   ✓ (a) *Escherichia coli, Salmonella typhi* (b) Chlorophyll *a*, carotenes, xanthophylls and phycobilins (phycocyanin, allophycocyanin and phycoerythrin) (c) *Azotobacter, Clostridium* (bacteria), *Anabaena, Nostoc* (cyanobacteria).

Two Mark Questions (Without Answers)

1. What structure does a bacterial chromosome denote ?
2. What do you mean by naked DNA ?
3. What do you mean by archaebacteria ?
4. What is plasmid ? Give its importance.

Three Mark Questions (Short Answer Type)

1. Differentiate between oxygenic and anoxygenic photosynthesis ?
2. What are (i) methanogens (ii) Halophiles (iii) thermoacidophiles ?
3. Differentiate between bacteria and cyanobacteria.
4. Discuss the various forms of bacteria.
5. Write what you know about chemoautotrophs.
6. What are antibiotics? Give five examples of bacteria producing antibiotics.
7. With the help of well labelled diagram describe the structure of a bacterial cell.
8. Draw a well labelled diagram of a cyanobacterial cell.

Five Mark Questions (Short Answer Type)

1. Write explanatory notes on (i) bacterial reproduction (ii) mycoplasma (iii) archaebacteria.
2. Why are blue green algae included under monera and not under plantae ? Discuss the importance of cyanobacteria.
3. Briefly describe the modes of reproduction in bacteria.
4. Draw a well labelled diagram of bacterial cell.

Miscellaneous Questions

1. Name the bacteria responsible for the following diseases: typhoid, tetanus and cholera.
2. Distinguish between: (a) Facultative anaerobes and facultative aerobes; (b) Photoautotrophs and chemoautotrophs; (c) Gram negative bacteria and gram positive bacteria.
3. Match the terms in column I with those in column II.

Column I	Column II
A. Cocci	i. true bacteria
B. Eubacteria	ii. archaebacteria
C. Chemoautotrophs	iii. spherical shape
D. Halophile	iv. iron bacteria
	v. rod shaped

Multiple Choice Questions (With Answers)

(1) Shape of *Staphylococcus* bacteria is (a) circular (b) oval (c) elongated (d) cubical. *(Kerala 2001)*
(2) In mycoplasma (PPLO) the plasmalemma is rich in
   (a) cellulose (b) myosin (c) glycogen (d) cholesterol. *(Kerala 2001)*
(3) A bacterial disease is (a) Tetanus (b) Polio (c) Filaria (d) Malaria. *(CET Chd. 2002)*
(4) Smallest bacterium is (a) *Dialister* (b) *Nitrosomonas* (c) *Bacillus* (d) *Spirillium*. *(CPMT 2002)*
(5) Site of bacterial respiration is (a) microsome (b) episome (c) mesosome (d) ribosome. *(R. PMT 2002)*
(6) Which one is peritrichous
   (a) *Pseudomonas* (b) *Bacillus typhosus* (c) *Spirillium* (d) *Vibrio*. *(MP PMT 2002)*
(7) Harmful substances released by bacteria are
   (a) antibiotics (b) toxins (c) antigens (d) allergins. *(AFMC 2003)*
(8) Trachoma is caused by
   (a) *Spirochaete* (b) *Chlamydia* (c) *Trichonympha* (d) *Paramecium*. *(CET Chd. 2003)*

(9) *Azolla* has a symbiotic relationship with
(a) *Chlorella* (b) *Anabaena* (c) *Nostoc* (d) *Tolypothrix*. *(CBSE 2004)*

(10) Bacterial ribosomes are (a) 70S (b) 60S (c) 80S (d) 50. *(Kerala 2004)*

(11) Disease associated with secretion of toxin is
(a) Tuberculosis (b) Tetanus (c) AIDS (d) Food poisoning *(AFMC 2005)*

(12) During retting of jute fibres, the fermenting microbe is (a) Butyric acid bacteria (b) *Streptococcus lactin* (c) *Helicobacter pylori* (d) Methanophilic bacteria. *(CBSE 2005)*

(13) Which one is wrong about *Frankia* ? (a) Can induce root formation in many plants. (b) Cannot fix vesicles in which nitrogenase is protected from oxygen by a chemical barrier of triterpine hopanoids. (c) Cannot fix nitrogen in free living state. (d) Like Rhizobium, it usually infects host through root hair deformation and stimulates cell proliferation in host cortex. *(CBSE 2005)*

(14) Curing of Tea leaves is accomplished by
(a) viruses (b) fungi (c) mycorrhiza (d) bacteria. *(CBSE 2006)*

(15) What is wrong about mycoplasma ?
(a) They are called PPLO (b) They are pleomorphic (c) They are sensitive to penicillin (d) They produce diseases in plants. *(CBSE 2007)*

(16) *Spirulina* belongs to kingdom (a) plantae (b) monera (c) protista (d) fungi. *(HPPMT 2007)*

(17) Which one does not belong to Monera ?
(a) Archaebacteria (b) Slime mould (c) Eubacteria (d) Mycoplasma. *(DPMT 2008)*

(18) Prokaryotic and eukaryotic flagella differ in
(a) type of movement and position (b) microtubular organisation and function (c) location and mode of functioning (d) microtubular organisation and type of movement. *(AFMC 2008)*

(19) *Thermococcus, Methanococcus* and *Methanobacterium* are
(a) Archaebacteria having eukaryotic histone homologue (b) Bacteria with cytoskeleton (c) Archabacteria with negatively supercoiled DNA as in eukaryotes but lacking histones. (d) Bacteria with positively coiled DNA, cytoskeleton and mitochondria. *(CBSE 2008)*

(20) A bacterium capable of tolerating extreme heat, dryness and toxic chemicals is probably having
(a) Thick wall (b) Endogenous buds (c) Endotoxins (d) Endospores. *(KCET 2009)*

(21) Oxygenic photosynthesis is found in
(a) *Oscillatoria* (b) *Chlorobium* (c) *Chromatium* (d) *Rhodospirillum*. *(CBSE 2009)*

(22) A free living anaerobic nitrogen fixer is (a) *Rhodospirillum* (b) *Rhizobium* (c) *Azotobacter* (d) *Beijernickia*. *(CBSE 2010)*

(23) Which is true of mycoplasma ? (a) They lack cell wall (b) They have the smallest cells (c) They can survive without oxygen (d) All the above. *(HP PMT 2010)*

(24) Which one of the following is denitritying bacteria ? (a) *Nitrosomonas* (b) *Pseudomonas* (c) *Azotobacter* (d) *Nostoc*. *(JK CET 2011)*

(25) In the 5-kingdom classification, the kingdom that includes the blue-green, algae, nitrogen-fixing bacteria and methanogenic archaebacteria, is (a) protista (b) monera (c) plantae (d) fungi. *(AMU (Med.) 2011)*

(26) A peculiar odour found in marshy areas and cow sheds is of gas produced by (a) mycoplasma (b) slime moulds (c) cyanobacteria (d) archaebacteria. *(DPMT 2011)*

(27) In eubacteria a cellular component that resembles eukaryotic cell is (a) nucleus (b) ribosome (c) plasma membrane (d) cell wall. *(CBSE 2011)*

(28) Which has wall-less smallest living cell (a) Cyanobacteria (b) Bacteriophage (c) Algae (d) Mycoplasma. *(HP PMT 2012)*

(29) Cyanobacteria are also referred as (a) Protists (b) Golden Algae (c) Slide Moulds (d) Blue-green algae. *(CBSE 2012)*

(30) Which is likely to be present in deep sea water (a) Saprophytic fungi (b) Archaebacteria (c) Eubacteria (d) Blue-green algae. *(NEET 2013)*

(31) Episome is a type of (a) Plasmid (b) Gene (c) Membrane (d) Cell wall. *(Odisha 2013)*

(32) Anoxygenic photosynthesis is characteristic of
(a) *Spirogyra* (b) *Chlamydomonas* (c) *Ulva* (d) *Rhodospirillum*. *(CBSE 2014)*

(33) *Trichodesmium erythraeum* which gives colour to Red Sea is
(a) Green alga (b) Blue-green alga (c) Red alga (d) Brown alga. *(EAMCET 2014)*

(34) Which of the following are not eukaryotes? (a) Monera (B) Protista (c) Animals (d) Plants. *(AMU 2014)*

(35) The organisms which each a cell wall and can live without oxygen are
(a) Thermoacidophiles (b) Methanogens (c) Archaebacteria (d) Mycoplasmas. *(KCET 2015)*

(36) The structures that help some bacteria to attach to rocks and/or host tissues are
(a) Rhizoids (b) Fimbriae (c) Mesosomes (d) Hold fast. *(CBSE 2015)*

(37) Primary producers of deep sea hydrothermal vent ecosystem are
(a) coral reefs (b) green algae (c) chemosynthetic bacteria (d) blue-green algae. *(NEET 2016)*

(38) Which among the following are the smallest living cells, known without a definite cell wall, pathogenic to plants as well as animals and can survive without oxygen ? *(NEET 2017)*
(a) *Pseudomonas* (b) Mycoplasma (c) *Nostoc* (d) *Bacillus*.

(39) Which of the following are found in extreme saline conditions ?
(a) Archaebacteria (b) Eubacteria (c) Cyanobacteria (d) Mycobacteria. *(NEET 2017)*

(40) Which of the following components provides sticky character to the bacterial cell ?
(a) Cell wall (b) Nuclear membrane (c) Plasma membrane (d) Glycocalyx. *(NEET 2017)*

(41) DNA replication in bacteria occurs (a) within nucleolus (b) prior to fission (c) just before transcription (d) during S phase. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as

(a) If both A and R are true and R is correct explanation of A
(b) If both A and R are true and R is not correct explanation of A
(c) If A is true and R is false. *(d) If both A and R are false*

1. **Assertion.** Cyanobacteria are photosynthetic blue green algae with prokaryotic structure.
Reason. They are green due to presence of chloroplasts. *(AIIMS 2000)*
A B C D

2. **Assertion.** Plasmids are strands of extrachromosomal DNA.
Reason. Plasmids are found in eukaryotic cells. *(Har. PMT 2000)*
A B C D

3. **Assertion.** *Escherichia coli*, *Shigella sp.* and *Salmonella sp.* are all responsible for diarrhoeal diseases.
Reason. Dehydration is common to all types of diarrhoeal diseases and adequate supply of fluids and electrolytes should be ensured. *(AIIMS 2006)*
A B C D

4. **Assertion.** True nucleus is absent in *E. coli* and other prokaryotes.
Reason. An undifferentiated, unorganised, fibrillar nucleus without any limiting membrane is found in prokaryotic cells. *(AIIMS 2007)*
A B C D

ANSWERS

Miscellaneous Questions

2. *Salmonella typhi* (= *S. typhos*), *Clostridium tetani*, *Vibrio cholerae*.
3. a — (iii), b — (i), c — (iv), d — (ii).

Multiple Choice Questions

(1) —a (2) —d (3) —a (4) —a (5) —c (6) —b (7) —b (8) —b (9) —b (10) —a
(11) —b (12) —a (13) —c (14) —d (15) —c (16) —b (17) —b (18) —d (19) —c (20) —d
(21) —a (22) —a (23) —d (24) —b (25) —b (26) —d (27) —c (28) —d (29) —d (30) —b
(31) —a (32) —d (33) —b (34) —a (35) —d (36) —b (37) —c (38) —b (39) —a (40) —d
(41) —b.

Assertion and Reason Type Questions

(1) —A (2) —B (3) —B (4) —A

2B KINGDOM PROTISTA

Kingdom of Unicellular Eukaryotes

The **Kingdom Protista** (Gk. *protistos* = first of all) was proposed by **Ernst Haeckel** (1866). Although all single-celled eukaryotes are placed in Kingdom Protista yet its boundaries are not well defined. What may be a photosynthetic protistan to one biologist may be 'a plant' to another. Phylogenetically the kingdom protista acts as a connecting link between the prokaryotic kingdom— Monera on one hand and the complex multicellular kingdoms— Fungi, Plantae and Animalia on the other hand. Protists are regarded as ancestors of all multicellular eukaryotic organisms.

Characteristic of Kingdom Protista

Occurrence

Protists are mostly aquatic organisms, therefore, they are found in the sea, fresh water and moist soil. Many protists are found in water bodies in the form of **plankton**. Some protists live in the bodies of animals as parasites.

Protist Structure

Protists are microscopic organisms. Cell structure is eucaryotic. It is surrounded by plasmalemma (cell membrane). There may be an outer covering of pellicle, cuticle, shell or cellulose wall. It contains organelles like mitochondria, Golgi complex, endoplasmic reticulum, 80S ribosomes, etc. Centrioles occur in a number of types. Photosynthetic forms contain chloroplasts with internal thylakoids. Cilia and flagella occur in a number of forms.

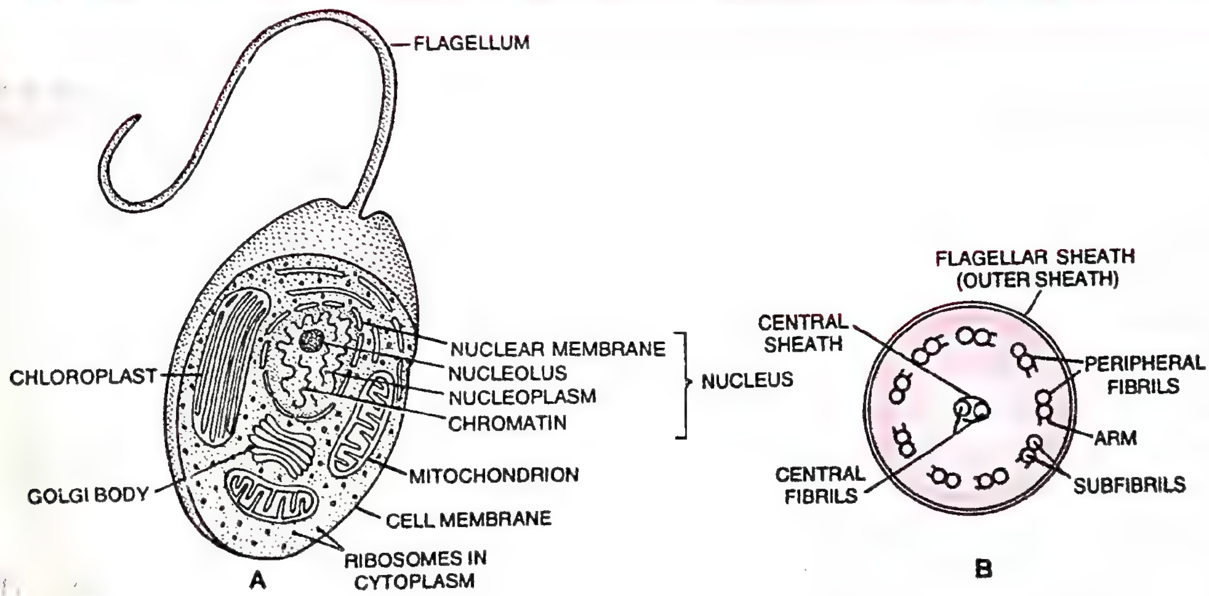


Fig. 2.21. A, typical photosynthetic Protist such as *Euglena* is schematically cut to show internal structure as revealed by the electron microscope. B, Cross section of the flagellum shows that it possesses 9 double peripheral and 2 single central fibrils.

They have typical 9+2 fibrils. Nucleus has typical structure—porous nuclear envelope, chromatin, nucleolus and nucleoplasm. Many forms have more than one similar or dissimilar nuclei.

Locomotion in Protists

Five modes of locomotion are recognised in the protista : pseudopodial, flagellar, ciliary wriggling and mucilage propulsion.

1. **Pseudopodial Locomotion.** It is slow creeping type of locomotion which is performed with the help of protoplasmic outgrowths called **pseudopodia.** Pseudopodial locomotion occurs in sarcodines and slime moulds. Pseudopodia are of four types : (i) **Lobopodia.** These pseudopodia are lobe-like with broad and blunt ends. These are present in *Amoeba.* (ii) **Filopodia.** These pseudopodia are fine, thread-like, tapering, and are composed of ectoplasm. These are found in *Euglypha.* (iii) **Axopodia.** These are long and stiff, with hard **axial filament.** These pseudopodia are present in *Actinophrys.* (iv) **Reticulopodia.** These are long and branching. The branches of adjacent pseudopodia may form network. These are found in *Globigerina.*

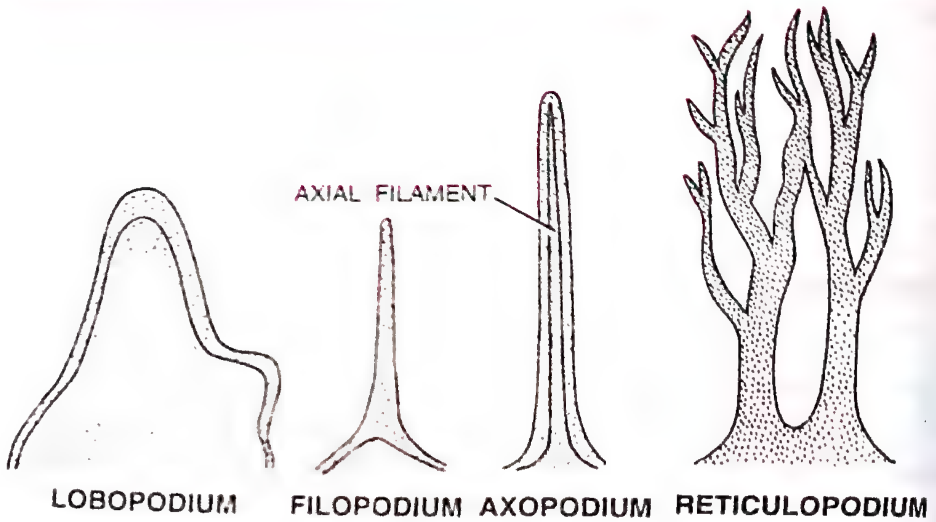


Fig. 2.22. Types of pseudopodia.

2. **Flagellar Locomotion.** Flagella show whip-like movement. They usually beat independently. This type of locomotion occurs in dinoflagellates (*e.g., Gonyaulax*), euglenoids (*e.g., Euglena*) and zooflagellates (*e.g., Leishmania*).

3. **Ciliary Locomotion.** Cilia show oar-like movement. All the cilia of a cell show coordinated movements which are of two types, **isochronic** and **metachronic** rhythms. In isochronic or **synchronous** rhythm, all the cilia of a cell beat simultaneously. They do so in rapid succession one after the other in case of metachronic rhythm. It occurs in ciliates (*e.g., Paramecium*).

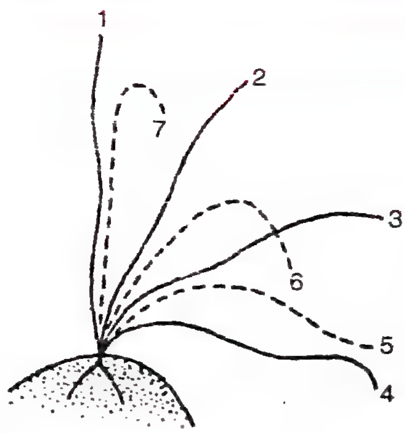


Fig. 2.23. Beating of a flagellum.

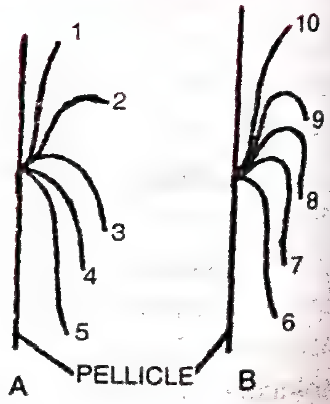


Fig. 2.24. Movement of a cilium. A, Effective stroke; B, Recovery stroke.

Basically flagella and cilia are identical in structure. However, they differ in some respects as mentioned below.

Cilia	*Flagella*
1. They are smaller in size. 2. Cilia usually occur throughout or major part of the surface of a cell. 3. They beat oar like and in a co-ordinated rhythm. 4. Cilia help in locomotion, feeding, circulation, etc. 5. Example : *Paramecium*.	1. They are larger in size. 2. Flagella are commonly found at one end of the cell. 3. The flagella beat whip-like and independently. 4. Flagella help in locomotion. 5. Example : *Euglena*.

4. **Wriggling Locomotion.** It is slow worm-like movement which is performed with the help of a wave of contraction and expansion in the body, *e.g.*, sporozoans, nonflagellates, euglenoids.

5. **Locomotion by Mucilage Propulsion.** Some protists like diatoms do not have any organelles of locomotion. They can, however, move from one place to another through secretion of mucilage. This type of locomotion occurs in the direction opposite to that of mucilage secretion.

Nutrition in Protists

Protists have following modes of nutrition.

1. **Photosynthetic (Holophytic)**. In this mode, the organisms prepare their food from CO_2 and water by utilising sunlight with the help of photosynthetic pigments like **chlorophyll**. The process is called **photosynthesis**. Examples are dinoflagellates, diatoms and euglenoids.

2. **Holozoic** or **Zootrophic** (Ingestive, Phagotrophic). In this mode, the individual captures and ingests the food like animals. It is found in many protozoans like *Amoeba* and *Paramecium*.

3. **Saprobic** or **Saprotrophic**. In this mode, the organism releases enzymes into the surroundings where the enzymes convert organic matter into simpler products. These products are then absorbed through body surface of the organism. Saprobic nutrition is found in **slime moulds**.

4. **Parasitic**. Some protists get their food from the body of other organisms. The individual which obtains its food is called **parasite** and the organism from which parasite gets food is called **host**. *Trypanosoma, Giardia, Entamoeba, Plasmodium* are some examples of parasites.

5. **Mixotrophic.** It is a mixed type in which the organism can perform two kinds of nutrition. For example, in *Euglena* nutrition is both holophytic and saprobic.

6. **Symbiotic**. Zooflagellates *Trichonympha* and *Lophomonas* live as a symbiont in the intestine of termites and wood roaches respectively. Both *Trichonympha* and *Lophomonas* secrete cellulose digesting enzymes which convert cellulose into glucose. The digested food (glucose) is shared by both zooflagellates and the hosts.

7. **Pinocytosis**. Soluble organic substances and salts are known to be absorbed in *Amoeba* and others through pinocytosis.

Respiration in Protists

Most of the free living protists perform aerobic respiration, however, the parasitic protists and protists living at the bottom of aquatic habitats respire anaerobically.

Reproduction in Protists

They reproduce by both asexual and sexual methods.

(a) **Asexual Reproduction.** It involves only one parent. All the young ones produced asexually have the same genetic constitution as that of the parent and are called **clones.** Asexual reproduction can occur in the following ways.

(i) **Binary fission.** It is the division of the parent body into two equal daughter individuals by mitosis. Examples : *Amoeba*, *Euglena* and *Paramecium.*

(ii) **Multiple fission.** It is the division of the parent organism into several daughter individuals. Examples : *Amoeba* and *Plasmodium.*

(iii) **Plasmotomy**. It is the division of the multinucleate protist into two or more multinucleate offspring by the division of cytoplasm without nuclear division. It occurs in *Opalina.*

(iv) **Spore formation.** In some protists **spores** are formed for asexual reproduction. Spores have some sort of covering to withstand unfavourable conditions. On germination, each spore gives rise to a new individual. Example : Slime moulds.

(v) **Budding.** In budding a small outgrowth develops from the parent body which separates and develops into a new individual. Example : *Arcella* (a Sarcodine)

(b) **Sexual Reproduction.** It originated in protists. Sexual reproduction involves two fundamental processes; **meiosis**, that reduces the number of chromosomes from 2n to 1n and **fertilization** or fusion of two 1n gametes to form a 2n zygote (fertilized egg). Meiosis is essential in sexual reproduction since it reduces the chromosome number to half in gametes so that after fertilization the number of chromosomes is kept constant in a species. There are two methods of sexual reproduction.

(1) **Syngamy.** It is complete fusion of two gametes to produce a diploid zygotes. Syngamy is of three types : (i) **Isogamy** (two fusing gametes are similar *e.g., Monocystis*); (ii) **Anisogamy** (two fusing gametes are dissimilar, *e.g., Ceratium*) and (iii) **Oogamy** (large non-motile gametes are fertilized by smaller motile gametes, *e.g., Plasmodium*).

(2) **Conjugation.** It is temporary union of two individuals to exchange their haploid pronuclei to from a zygote nucelus. Each individual with zygote nucleus produces daughter invidiuals by binary fission. It occurs in *Paramecium.*

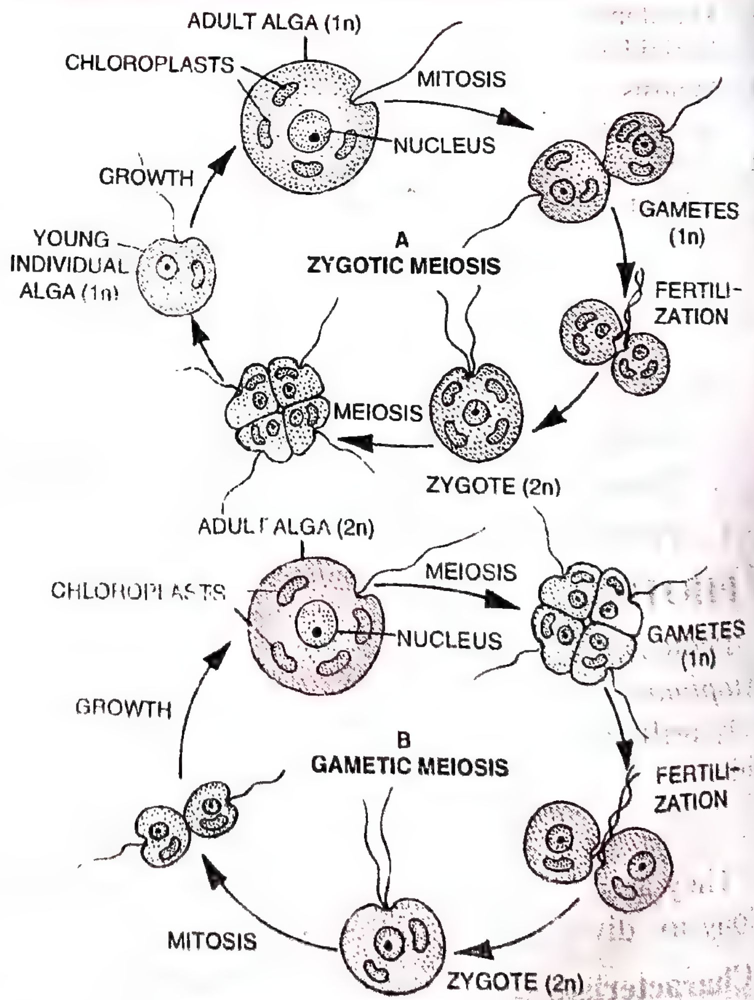


Fig. 2.25. A, Life cycle showing zygotic meiosis; B, Life cycle showing gametic meiosis.

Life Cycles in Protists (Fig. 2.25).

The sequence of events between any given phase in one generation and that similar phase in the next succeeding generation constitute a **life cycle.** Two types of life cycles are found in protists.

(a) **Life Cycle Showing Zygotic Meiosis.** It occurs in some dinoflagellates (*e.g., Ceratium, Gymnodinium*; von Stosch, 1973) and cellular slime moulds. The zygote is 2n that divides by meiosis (also called zygotic meiosis) and produces vegetative cells with 1n chromosome number. These cells divide repeatedly by mitosis and all the resulting daughter cells maintain the 1n number of chromosomes. Some of the vegetative cells produce gametes. When these gametes combine in fertilization, a zygote is formed and the life cycle is completed.

(b) **Life Cycle Showing Gametic Meiosis.** This is found in the majority of protozoan protists, diatoms and acellular slime moulds. The organism spends most of its life cycle in the 2n condition. The gametes are only 1n (haploid) that are produced by meiosis (also called **gametic meiosis**). The gametes fuse to form zygote that grows to form the diploid individual.

Differences in the Life cycles showing Zygotic meiosis and Gametic meiosis

Life cycle with Zygotic meiosis	*Life cycle with Gametic meiosis*
1. Zygote is the only diploid structure in the life cycle.	1. All structures except gametes are diploid.
2. The dominant individual in the life cycle is haploid hence the life cycle is haplontic.	2. The dominant individual in the life cycle is diploid hence the life cycle is diplontic.
3. Meiosis takes place at the time of zygote germination.	3. Meiosis occurs only at the time of gamete formation.
4. It is found in some dinoflagellates and cellular slime moulds.	4. It is found in most protozoan protists, diatoms and acellular slime moulds.

MAJOR GROUPS OF PROTISTS

The kingdom Protista has been broadly divided into three main groups.

A. Photosynthetic Protists (Protistan Algae).

B. Consumer-Decomposer Protists (Slime Moulds)

C. Protozoan Protists

A. PHOTOSYNTHETIC PROTISTS (PROTISTAN ALGAE)

Photosynthesis takes place in these protists. They constitute the main portion of the *phytoplankton.* The phytoplankton are the green photosynthetic organisms which are passively drifted by the water current. They include dinoflagellates, chrysophytes and euglenoids.

(1) DINOFLAGELLATES

They are a group of about 1,000 species of photosynthetic protists. The dinoflagellates belong to division **pyrrophyta** and class **dinophyceae.**

Characteristic Features of Dinoflagellates

Habitat and Habits. (i) The dinoflagellates are important component of phytoplankton. *Most of them are marine but some occur in fresh water.* Some dinoflagellates such as

Gymnodinium and *Gonyaulax* grow in large number in the sea and *make the water look red* and cause the so called **"red tide"**. (ii) Some periplast covered golden dinoflagellates called **zooxanthellae** occur in a number of marine protozoan protists (ciliates, radiolarians, foraminiferans) and invertebrates (sponges, corals, jelly fishes, gastropods, etc.). (iii) Some marine dinoflagellates show **bioluminescence**. It means they emit light, *e.g., Noctiluca, Gonyaulax, Pyrocystis, Pyrodinium.* (iv) Nutrition is photosynthetic.

Structure. (i) Dinoflagellates are basically unicellular motile and biflagellate, golden brown, photosynthetic protists. Predominant colour is golden brown but yellow, green, brown and even blue forms also occur due to change in proportion of various pigments. A few are nonmotile, nonflagellate, amoeboid, filamentous. (ii) Cells are generally covered by a rigid coat the **theca** or **lorica** of articulated and sculptured plates of **cellulose**. Periplast may occur instead of theca. Because of the presence of sculptured plates, these protists are often known as **armoured dinoflagellates**. (iii) The theca contains two grooves, the longitudinal groove called the **sulcus** and the circular groove known as the **cingulum** or **annulus** or **girdle**. (iv) The **two flagella** are different (heterokont), one transverse flagellum and other longitudinal flagellum. The longitudinal flagellum is narrow, smooth, directed posteriorly and lies in the sulcus. The transverse flagellum is ribbon-like and lies in the cingulum or annulus. The two types of flagella beat in different directions. This causes spinning of dinoflagellates while swimming in water. (v) The nucleus is larger in size and has been named as **mesokaryon** by **Dodge** (1966). Chromosomes do not have histone or RNA. (vi) Plastids or chromatophores have **chlorophyll** ***a*** and **chlorophyll** ***c***. (vii) Mucilage bodies or vesicles occur below the cell membrane. (viii) A noncontractile vacuole called **pusule** is present near the flagellar base. Pusule may take part in floatation and osmoregulation. *Contractile vacuoles are absent.* (ix) Varieties of eye spots occur in dinoflagellates. Some of them are like ocelli. (x) **Trichocysts** are found in a number of dinoflagellates. **Nematocysts** have also been reported in a few dinoflagellates.

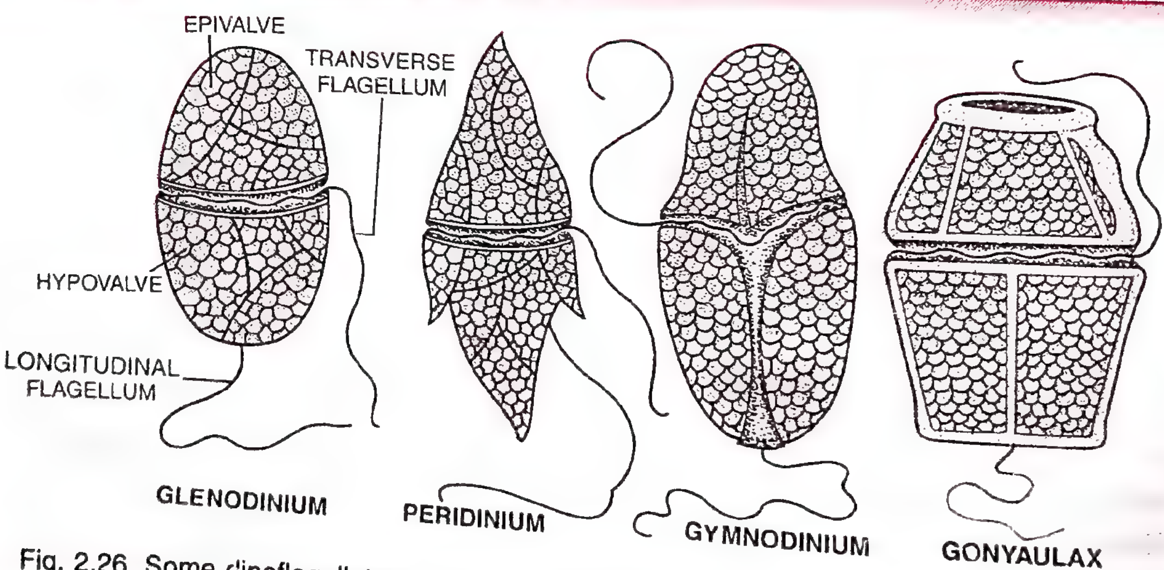


Fig. 2.26. Some dinoflagellates. Note the plates that surround the body and two flagella, one transverse in a groove and other free and longitudinal.

Reserve Food. Reserve food is stored in the form of starch and oils.

Reproduction. (i) Asexual reproduction is commonly through cell division. Cysts occur in a number of dinoflagellates. (ii) Sexual reproduction has been reported in some dinoflagellates (*e.g., Ceratium*). It is isogamous and anisogamous. (iii) The life cycle involves zygotic

meiosis in *Ceratium, Gymnodinium* and *Woloszynskia*. Gametic meiosis occurs in *Noctiluca*.

Examples. *Glenodinium, Peridinium, Gymnodinium, Gonyaulax, Ceratium, Noctiluca.*

Economic Importance of Dinoflagellates. Some dinoflagellates (*e.g., Gonyaulax catenella*) are poisonous to vertebrates. When they are in large number, they produce the toxin called saxitoxin into the sea water which kills fishes and other aquatic animals. Marine shell fishes (sea mussels-molluscs) eat large number of dinoflagellates. The poisonous substance of dinoflagellates reach the shell fishes. The poison is not harmful to the shell fishes but the consumption of these infected mussels by man causes severe illness called **paralytic shell fish poisoning (PSP)** and may be fatal.

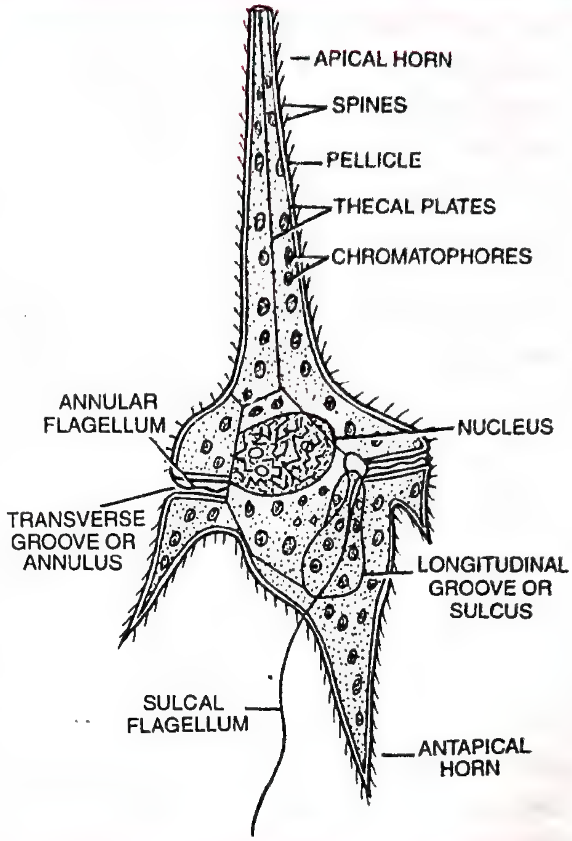


Fig. 2.27. *Ceratium.*

Ceratium. It is a heavy armoured dinoflagellate which occurs in marine, brackish and fresh waters. Sexual reproduction is anisogamous. Male gametes are small. Cytoplasm possesses a large mesokaryotic nucleus and a number of scattered chromatophores.

Noctiluca (= **The Night Light**). It is a **colourless dinoflagellate** which is an important constituent of coastal plankton of both temperate and tropical seas. Nutrition is **holozoic**. Gametes are similar (isogametes). This alga is famous for **bioluminescence** as it was the first dinoflagellate where bioluminescence was reported. It is characterised by the presence of a fragile long **tentacle** that functions as a flagellum. The transverse flagellum is reduced into a tooth-like structure. The longitudinal flagellum is small. The sulcus is developed into an oral groove and a cytostome. Tentacle develops beneath the cytostome.

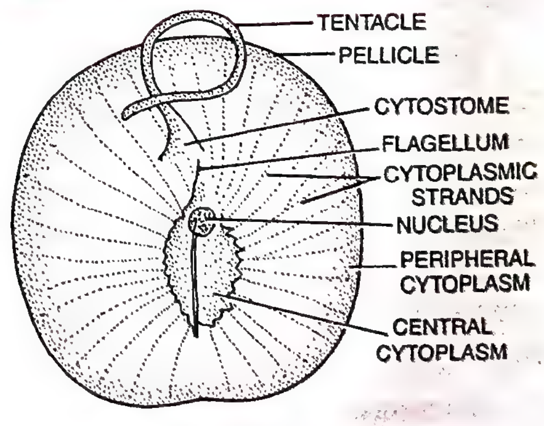


Fig. 2.28. *Noctiluca.*

(2) CHRYSOPHYTES

Chrysophytes include **diatoms** and **desmids**. They belong to the division **Chrysophyta/ Bacillariophyta**.

(i) Diatoms

Habitat and Habits. (i) Diatoms occur in all aquatic and moist terrestrial habitats. (ii) They may be free floating or bottom dwellers. The free floating forms remain suspended on the surface of water by mucilage secretion and presence of light weight lipids. (iii) Diatoms may show gliding type of movement with the help of mucilage. (iv) The siliceous frustules of diatoms do not decay easily. They pile up at the bottom of water reservoirs and form big heaps called **diatomite** or **diatomaceous earth**. It may extend for several hundred metres in certain areas from where the same can be mined.

Structure. (i) The body is covered by a transparent **siliceous shell** (silica deposited in cell wall) known as **frustule**. The frustule is made of two valves, **epitheca** and **hypotheca**. The two valves fit together like a soap box. The frustule possesses very fine markings, pits, pores and ridges. (ii) Diatoms are microscopic, variously coloured and of diverse forms protists which **do not possess flagella** except in the reproductive state. (iii) They are basically unicellular but can form pseudofilaments and colonies. (iv) Depending upon the symmetry, the diatoms are of two types namely, **pennate** and **centric**. The pennate diatoms show bilateral symmetry *e.g.*, *Navicula* and the centric diatoms have radial symmetry, *e.g.*, *Melosira*. (v) Each cell has a large central vacuole. The **single large nucleus** is commonly suspended in the central vacuole by means of cytoplasmic strands. (vi) Chloroplasts or chromatophores are yellowish brown to greenish brown. They contain **chlorophyll *a*** and **chlorophyll *c***. (vii) Diatoms contain **fucoxanthin** (typical of brown algae) that provides brownish tinge.

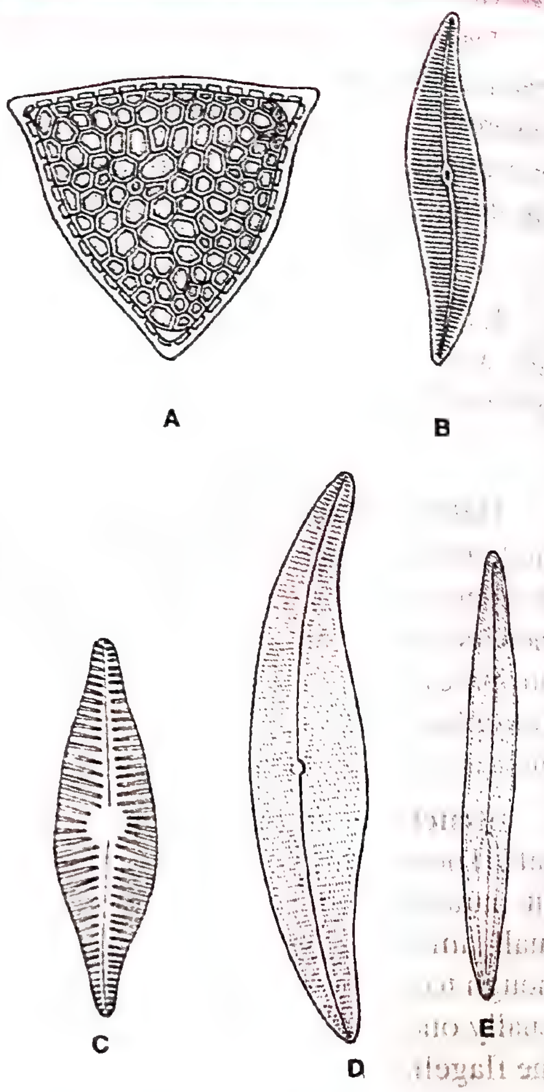


Fig. 2.29. Some common diatoms. A, *Triceratium*; B, *Pleurosigma*; C, *Navicula*; D, *Cymbella*; E, *Amphipleura*.

Reserve food. The food is reserved in the form of **oils** and **leucosin** (polysaccharide). **Volutin globules** (proteinaceous in nature) are also present.

Reproduction. (i) The common mode of multiplication is by **binary fission**. (ii) Resting spores or statospores are formed in some cases. (iii) Meiosis is gametic. Sexual reproduction varies from isogamy to oogamy. In the latter case, male gametes are motile and uniflagellate. Fertilization produces a zygote which grows in size and forms a rejuvenascent cell called **auxospore**. (iv) Diatoms are unusual in that their vegetative cells are typically diploid.

Examples. *Triceratium, Pleurosigma, Navicula, Cymbella, Amphipleura.*

Economic Importance of Diatoms. (i) Diatoms are very important photosynthesisers. About half of all the organic matter synthesised in the world is believed to be produced by them. Though microscopic, diatoms are an important source of food to aquatic animals. A 60 tonne blue whale may have 2 tonne of plankton in the gut which is mostly diatoms. (ii) The oils extracted from some fishes and whales are actually the ones produced by diatoms. (iii) Diatomite deposits are often accompanied by petroleum fields. Much of the petroleum of today is probably due to decayed bodies of the past diatoms. (iv) Diatomite is porous and chemically inert. It is, therefore, used in filtration of sugar, alcohols oil, syrups and antibiotics. (v) Diatomite is employed as a cleaning agent in tooth pastes and metal polishes. (vi) Diatomite is added to paints for enhancing night visibility. (vii) Diatomite is employed as insulation material in refrigerators, boilers and furnaces. (viii) Diatomaceous earth is added to make sound proof rooms. (ix) Diatomite is a good industrial catalyst. (x) Diatomite is a source of water glass or sodium silicate. (xi) Diatoms are very good **pollution indicators**.

(ii) Desmids.

Desmids are unicellular green algae. Like *Spirogyra*, they have an elaborate chloroplast. Their cells have two distinct halves. The outer wall of the cell has various protuberances covered with mucilaginous sheath which is thought to play a role in the cell's slow gliding movement. Sexual reproduction occurs by 'conjugation' similar to that of *Spirogyra*. They are mainly found in fresh water and are usually indication of clean (unpolluted) water.

(3) EUGLENOIDS

Euglenoids are **Euglena like unicellular flagellates** which possess pellicle instead of cell wall. They belong to division **euglenophyta** and class **euglenophyceae**. They were previously placed under class *Phytomastigophora* of Protozoa by zoologists.

Characteristic Features of Euglenoids

Habitat and Habits. (i) Euglenoids occur in fresh water habitats and damp soils. (ii) Euglenoids swim actively in a liquid medium with the help of their long flagellum. They can also perform creeping movements by expansion and contraction of their body. This phenomenon is called **metaboly** or euglenoid movements. (iii) Nutrition is holophytic (photoautotrophic), saprobic or holozoic. In dark even photosynthetic forms can behave like heterotrophic, predating on smaller organisms (holozoic) or feeding on organic remains (saprobic). Such a mode of nutrition is called **mixotrophic** (*e.g., holophytic + saprobic or holozoic*).

Structure. Euglenoids are unicellular flagellate protists. They are without cellulose cell wall. The body is covered by thin and flexible **pellicle (= periplast)**. The pellicle has oblique but parallel stripes called **myonemes**. The pellicle is composed of fibrous elastic protein, small amount of lipid or/and carbohydrates and maintains a definite shape. It is flexible enough to permit temporary changes in the body shape. (ii) The euglenoids have two flagella, usually one long and one short. Each flagellum arises from a basal granule (= **blepharoplast**). The flagella bear hair (= **tinsels**). So the flagella are tinsel type. (iii) The apical end bears an invagination having three parts— **cytostome**, **cytopharynx** and **reservoir**. The cytostome is generally eccentric. (iv) Just in the area of union of two roots, the flagellum bears a swelling called **paraflagellar body**. An orange-red **eye spot** or **stigma** occurs attached to the membrane of reservoir at the level of paraflagellar body. Eye spot contains red pigment **astaxanthin**, found elsewhere only in crustacea. Both paraflagellar body and eye spot perceive the stimulus of light. They help in directing the organism toward the optimum light. (v) An osmoregulatory contractile vacuole occurs in the anterior part of the cell below the reservoir. It is fed by a number of canals. The contractile vacuole discharges its contents into the reservoir. (vi) The photoautotrophs or holophytic forms possess **chloroplasts** with or without pyrenoids. Photosynthetic pigments include **chlorophyll *a*** and **chlorophyll *b***. (vii) A single large nucleus lies roughly in the middle. The nuclear envelope persists during division. The nucleolus also persists and divides into two.

Reserve Food. They store their carbohydrates as **paramylon** or **paramylum bodies**. The latter are formed outside the chloroplasts. Paramylum bodies are scattered throughout the cytoplasm. Paramylum is chemically different from starch and glycogen and does not stain with iodine.

Reproduction. Sexual reproduction has not yet been definitely proved. Under favourable conditions, euglenoids multiply by **longitudinal binary fission.** The **palmella stage** is found during unfavouble conditions.

Examples. *Euglena, Phacus, Eutreptia, Trachelomonas, Peranema.*

***Euglena*— The Spindle Organism.** *Euglena* (Gk. *eu*– good, *glene*– eyeball) is a large genus having 152 species (Gojdics, 1953). The common species is *E. viridis*. It is found in fresh water ponds and pools. It also occurs on moist mud (Lackey, 1968). *Euglena* is a free living solitary and unicellular flagellate. *Euglena* is **mixotrophic** (holophytic + saprobic) in nutrition. Holozoic or phagotrophic forms are absent. Asexual reproduction occurs by **longitudinal binary fission.** Sexual reproduction has not yet been recorded. Perennation occurs through cyst formation. The body is covered by a plasma membrane followed by periplast or **pellicle**. The pellicle is made up of proteins (about 80%), carbohydrates and lipids. Besides swimming *Euglena* can also perform creeping movements or **metaboly**. At the place of union of the two branches, the flagellum bears a swelling called **paraflagellar body (photoreceptor)**. The posterior end is pointed. The anterior end of the cell is blunt and bears an eccentric **cytostome** (mouth). The cytostome leads into a tubular canal, also called **cytopharynx** (gullet). The latter expands at the base to form a large rounded **reservoir**. At one end of the reservoir, the cytoplasm contains an orange red **stigma** (eye spot). The latter is photosensitive. Just below the reservoir is found a **contractile vacuole** having many **feeding canals** (= accessory vacuoles). The contractile vacuole takes part in osmoregulation. It expands and pumps its fluid contents in the reservoir. Chloroplasts are numerous, discoid shaped or ribbon-like. **Pyrenoids** (proteinaceous bodies) may be present in the chloroplasts. Chlorophyll *a* and chlorophyll *b* are present. The endoplasm contains several **paramylum bodies**. They have polysaccharide called **paramylon** or **paramylum** (β-1,3 glucan).

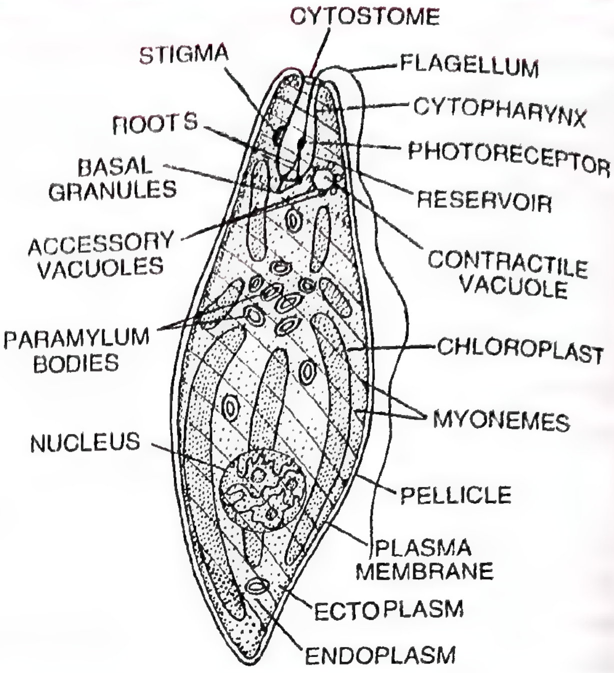


Fig. 2.30. *Euglena*.

Euglena is studied as plant as well as animal. It is called plant animal. **Plant Characters of *Euglena*.** (i) Presence of chloroplasts with chlorophyll. (ii) Holophytic (photosynthetic) nutrition. **Animal Characters of *Euglena*.** (i) Presence of pellicle which is made up of proteins and not of cellulose. (ii) Presence of stigma and paraflagellar body (photosensitive structures). (iii) Presence of contractile vacuole (not found in plants). (iv) Presence of longitudinal binary fission.

B. CONSUMER-DECOMPOSER PROTISTS— SLIME MOULDS

Slime moulds possess the characters of both animals and fungi and, therefore, they are commonly called **fungus-animals**. Anton De Bary (1887) related them to animals and called them **Mycetozoa** (Gk. *mykes* - fungus, *zoon* = animal). Mycologists like Mac Birde (1899), included them in the division **Myxomycota** (Gk. *myxa* = slime, *mykes* = fungus). Modern biologists include slime moulds under the kingdom **Protista** and call them **protistan fungi**.

General Characters of Slime Moulds

(1) They do not have chlorophyll. (2) They are surrounded by the plasma membrane only (somatic parts are without cell walls). However, the spores have the cellulose cell walls. (3) At one stage of the life cycle they have amoeboid structure. (4) The slime moulds live usually

amongst decaying vegetation. They are quite common on lawns and moist fields. (5) They exhibit wide range of colouration. (6) They have **phagotrophic** or **saprotrophic** nutrition. Parasitic forms are not known (Bold *et al*, 1987). (7) Both asexual and sexual modes of reproduction are found. They produce spores within sporangia. A spore possesses a cell wall of cellulose. (8) The slime moulds resemble both protozoa and the true fungi. They are like protozoa in their amoeboid plasmodial stage and similar to true fungi in spore formation.

Types of Slime Moulds. Slime moulds are of two types : *acellular* and *cellular.*

(a) **Acellular Slime Moulds (= Plasmodial Slime Moulds)**

1. **Habitat.** These moulds are commonly found on dead and decaying leaves, twigs, logs of wood and the other decaying vegetable matter. They prefer to grow in damp places rich in decaying vegetable matter in the forests a little after and during the rainy seasons.

2. **Somatic Phase.** It is **diploid** multinculeate **plasmodium.**

3. **Plasmodium.** A free living **thalloid body** of the acellular slime moulds is called **plasmodium.** The plasmodium is wall-less mass of multinucleate protoplasm covered by slime. All the nuclei in the plasmodium divide simultaneously. The plasmodia (*pl.* of plasmodium) are often coloured. They may be even colourless. However, chlorophyll is always absent. The plasmodium often possesses a number of branched **"veins"**. The protoplasm present in the veins shows reversible streaming movement. The **"veins"** disappear and reappear as the plasmodium moves about. The plasmodium creeps over the surface of the substratum with the help of pseudopodia. Internally the plasmodium has contractile fibrils and streaming cytoplasm alongwith eukaryotic organelles except plastids. The chief mode of nutrition of plasmodium is saprotrophic, absorbing the organic food from the decaying organic matter. Plasmodium also feeds on bacteria, protozoa, spores of fungi and other microorganisms through ingestion and engulfing (*i.e.*, phagotrophic or holozoic nutrition).

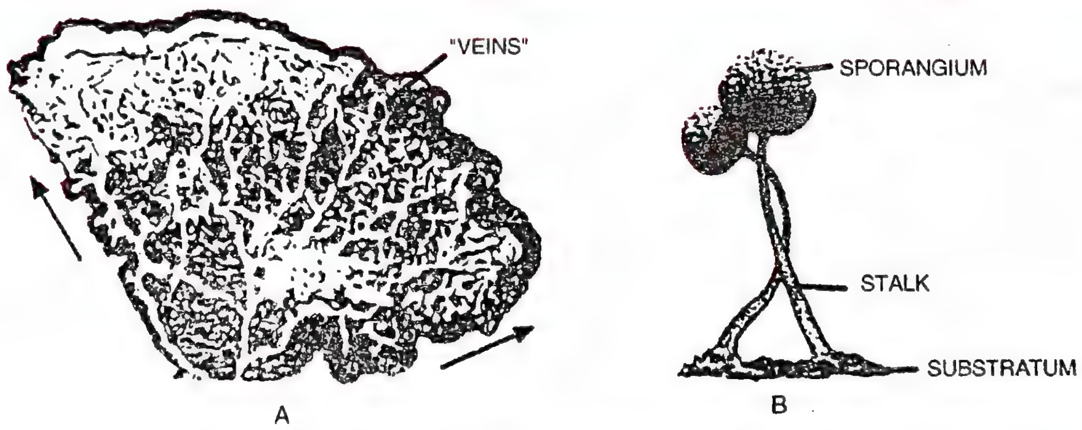


Fig. 2.31. *Physarum.* A, Plasmodium —advancing in the direction of the arrows. B, Sporangia on stalks developed from the plasmodium.

4. **Plasmotomy.** During injury, the plasmodium (multinucleate) may undergo division to form two or more plasmodia.

5. **Perennation.** Perennation means surviving from year to year by vegetative means. Under unfavourable conditions such as drought or too much cold, the plasmodium divides to form two types of perennating structures : (i) **Cyst.** Plasmodium divides into small multinucleate fragments. Each fragment secretes a thick covering to form a cyst. (ii) **Sclerotium.** Sometimes the whole plasmodium secretes a thick covering around itself called **sclerotium.** Cyst and Sclerotium can remain dormant for a few months

to many years. On return of favourable conditions, the cyst or the sclerotium releases the multinucleate plasmodium. Thus these structures serve for perennation.

6. **Life Cycle**. (i) **Sporangia.** When the plasmodium reaches a certain stage of maturity or the food supply is nearly exhausted, the contents of plasmodium concentrate at one or more places forming papilla like mounds that grow into sessile or stalked **sporophores**. Each sporophore bears one or more **sporangia** (= **fruiting bodies**). Each sporangium is surrounded by a hard and brittle wall-like layer, the **peridium.**

(ii) **Spores**. The numerous diploid nuclei in the sporangium undergo meiotic division. The multinucleate protoplasm of the sporangium undergoes cleavage to form uninucleate tiny segments. Each uninucleate tiny segment becomes rounded and secretes a cell wall to become **spore**. The sporangium also develops a system of threads called **capillitium**. When fully mature, the wall of the sporangium bursts to release the spores. The spores are dispersed by air. Spores of some species such as *Fuligo septica*, cause allergic reactions.

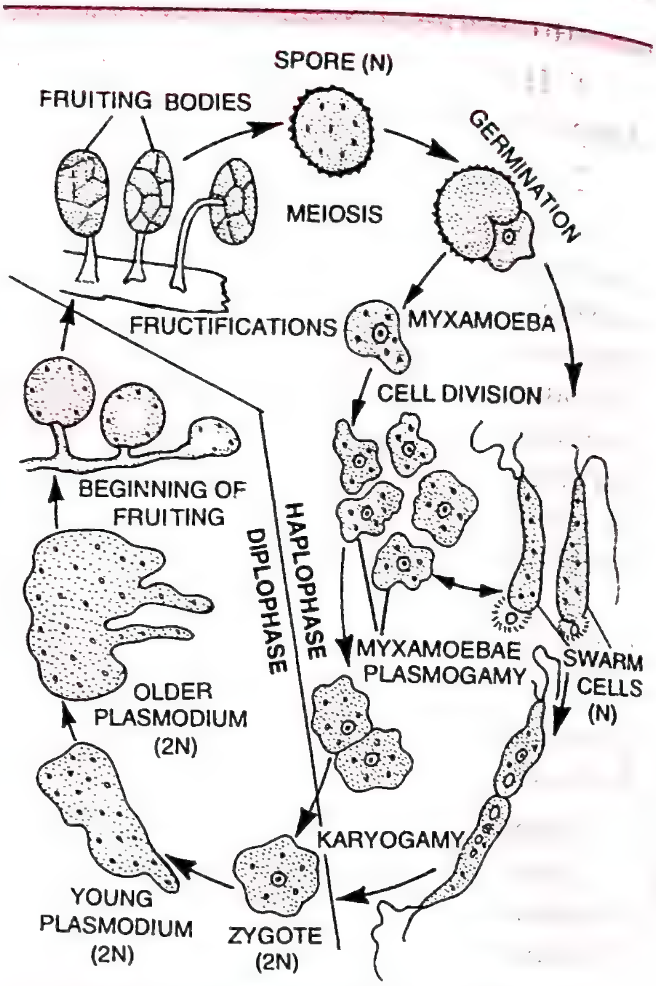


Fig. 2.32. Life cycle of an acellular slime mould.

(iii) **Germination and Sexual Reproduction**. After falling on a suitable substratum, each spore germinates only when water is available. On germination, a spore generally releases one biflagellate, spindle-shaped **swarm cell** or a non-flagellate **myxamoeba.** The myxamoeba feeds on bacteria and yeasts and multiplies in number. Ultimately myxamoebae fuse in pairs to form zygote. The swarm cells swim about actively and finally fuse in pairs at the posterior nonflagellate ends to form zygote.

(iv) **Formation of Plasmodium**. The zygote creeps over the substratum and feeds on the bacteria, yeasts and the other organic matter. It grows in size and diploid nucleus of the zygote undergoes repeated mitotic divisions. As a result, the zygote gradually changes into a multinucleate amoeboid structure the **plasmodium**. The plasmodium repeats the life cycle.

Examples of Acellular Slime Moulds. *Physarum, Physarella, Fuligo, Dictydium, Lycogala, Tubifera.*

Differences Between *Plasmodium* and Plasmodium

Plasmodium	**Plasmodium**
1. It is a genus of malarial parasite.	1. It is a somatic body of acellular slime moulds.
2. It is uninucleate.	2. It is multinucleate.
3. It is parasite.	3. It is free living.
4. Nutrition is by absorption.	4. Nutrition is by ingestion.

(b) **Cellular Slime Moulds** (Acrasiomycetes).

1. **Habitat**. The cellular slime moulds occur in all humus-containing upper layers of damp soil.

2. **Somatic Phase**. It is represented by **haploid** and uninucleate cells called **myxamoebae.**

3. **Myxamoebae**. These are **uninucleate, haploid** and **amoeba-like** cells. *Myxamoebae are without cell wall.* They are covered by plasma membrane. They move by amoeboid movements. Myxamoebae feed on bacteria and other microorganisms through ingestion (phagotrophic or holotrophic nutrition). They grow and divide to form a large population of individuals. Under unfavourable conditions, a myxamoeba secretes a rigid cellulose wall to form the **microcyst.** Microcyst formation is a means of perennation. The microcysts can be dispersed. On the return of favourable conditions, the microcyst wall ruptures to release a myxamoeba. The latter resumes its function of feeding, growth and multiplication forming amoeboid cells.

4. **Life Cycle.** (i) **Pseudoplasmodium**. When the food supply is exhausted, the amoeboid cells get aggregated without any fusion. The stimulus for the aggregation process is due to release of cyclic adenosine monophosphate (cyclic AMP) from the amoeboid cells. This aggregated mass of cells is called **pseudoplasmodium**. It is a sort of community association. Because of this reason, cellular slime moulds are called the **communal slime moulds**.

Significance of Pseudoplasmodium. The pseudoplasmodium exhibits a primitive form of multicellularity, where cells maintain their identity but can live together. It also shows division of labour as some cells form fruiting body (sporangium) while others form spores. For this reason the cellular slime moulds are regarded as advanced protists or primitive fungi.

(ii) **Sporangium**. The aggregated cells of pseudo-plasmodium differentiate and migrate to form a stalked **sporocarp**. The sporocarp bears a sporangium at its terminal end. The sporangium of cellular slime moulds is naked. The stalk may remain upright or become slightly bent.

(iii) **Spores**. The cells present inside the sporangium become rounded and are surrounded by the cellulose wall to form the **spores** . Each spore is an ovoid, haploid, uninucleate mass of protoplast *covered by a cellulose cell wall.* The spore germinates to produce a single naked amoeba like cell called **myxamoeba**.

(iv) **Sexual Reproduction in Cellular Slime Moulds**. Sexual reproduction in cellular slime moulds is controversial. In this process, the myxamoebae form clusters. The central myxamoeba of the cluster engulfs a surrounding myxamoeba to become larger structure which forms a thick wall to form the **zygote**. This zygote is called **macrocyst**. Karyo-

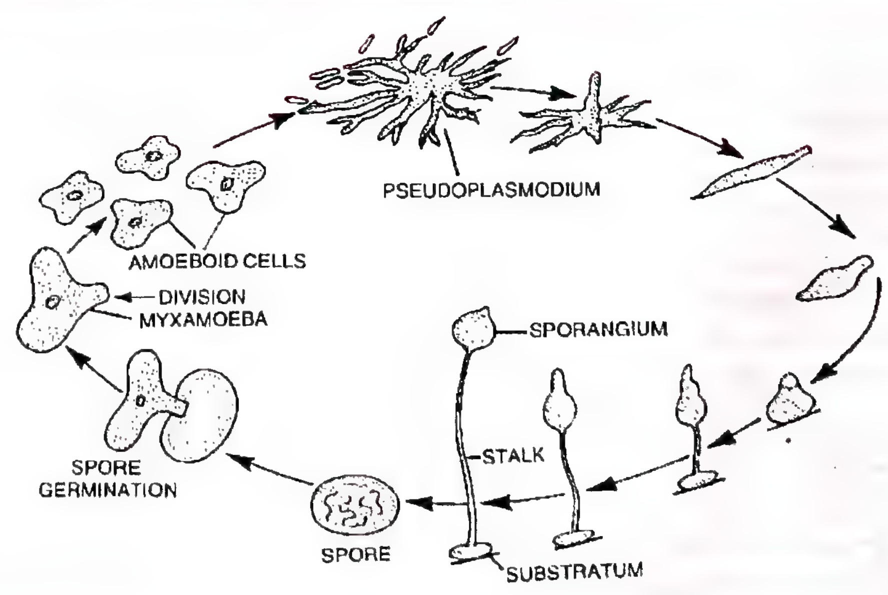


Fig. 2.33. Life cycle of cellular slime mould.

gamy occurs inside the macrocyst which is followed by meiotic and several mitotic divisions. Ultimately the macrocyst wall ruptures to release a number of haploid myxamoebae.

Examples of Cellular Slime Moulds. *Dictyostelium, Polysphondylium.*

The cellular slime moulds have the characters of both plants and animals. The reproductive phase is plant-like as the spores have a cell wall composed of cellulose. However, vegetative phase is animal like having no cell wall and feeding like amoeba.

Significance of Slime Moulds. (i) The slime moulds cause the decay and decomposition of the organic matter in the soil. (ii) They creep over the ornamental plants and make them look ugly. (iii) Their attractive colours are of artistic value. (iv) The plasmodia of slime moulds are an excellent material for the study of structure and physiology of protoplasm.

Differences Between Plasmodium and Pseudoplasmodium

Plasmodium	*Pseudoplasmodium*
1. It is a free-living multinucleate amoeboid mass of protoplasm.	1. It is an aggregated mass of amoeboid cells where each cell maintains its separate identity
2. Plasmodium is found in acellular slime moulds.	2. Pseudoplasmodium is found in cellular slime moulds.

C. PROTOZOANS

Protozoans were first studied by **Leeuwenhoek** (1677). The name "Protozoa" was coined by **Goldfuss** (1817). The branch of biology which deals with protozoa is called **protozoology**.

Classification of Protozoans

On the basis of locomotory organelles, the protozoans are divided into four groups: Flagellated Protozoans, Amoeboid Protozoans, Sporozoans and Ciliated Protozoans.

Group 1. Flagellated Protozoans

Characters. (i) They possess flagella for locomotion. (ii) They may be free living aquatics, parasites, commensals or symbionts. (iii) Zooflagellates are generally uninucleate, occasionally multinucleate. (iv) The body is covered by a firm pellicle. (v) Nutrition is holozoic, saprobic and parasitic. (vi) Asexual reproduction is by binary fission. (vii) Sexual reproduction is recorded in some forms only.

Examples. *Trichonympha, Lophomonas, Giardia, Trypanosoma, Leishmania* and *Trichomonas*. *Trichonympha* and *Lophomonas* are cellulose digesting symbionts in the body of termites and wood roaches respectively. The others are parasites in human beings.

1. ***Trypanosoma gambiense*— The parasite of sleeping sickness.** It was first observed by **Forde** in 1901. **Fruce** discovered that the parasite of sleeping sickness is transmitted by tse-tse fly. It causes **Gambian sleeping sickness**. The disease, also called **Gambian trypanosomiasis**, is found in western and central parts of Africa. The parasite is transmitted by blood sucking **tse-tse fly**, *Glossina palpalis*. The reserve host is antelope. The parasite does not affect antelope and the fly. Mouth and contractile vacuole are absent. Food is absorbed through the body surface. In human beings the parasite lives in the blood plasma.

Later the parasite enters cerebrospinal fluid and damages the brain. It makes the patient lethargic and unconscious.

2. ***Trypanosoma rhodesiense***. It causes **Rhodesian sleeping sickness**. The disease is also called **Rhodesian trypanosomiasis**. The parasite is transmitted by the bites of tse tse fly (*Glossina palpalis* and *Glossina morsitans*). Initially parasite is present in the blood of man but later on it enters the cerebrospinal fluid.

3. ***Trypanosoma cruzi***. It causes **South American trypanosomiasis** (also called **Chagas disease**). The symptoms of the disease are fever, diarrhoea, anaemia and enlargement of lymphoid glands. Human beings become infected by contamination of wounds, etc., with faeces of **triatomid bugs**.

Polymorphism in *Trypanosoma*. During life cycle, trypanosomas multiply and modify into four main types of **polymorphic forms** which differ from each other in the form of the body and arrangement of organelles.

4. ***Leishmania donovani****. It causes **kala-azar** or **dum-dum fever (= visceral leishmaniasis)**. Kala-azar means black sickness. This disease is quite common in East Asia including India, parts of Africa and America. The fever is continuous and is accompanied by anaemia, enlargement of liver, spleen, etc. The parasite is transmitted by **sandfly**, *Phlebotomus argentipes* and other species. Dogs and cats function as reservoir host. The parasite lives inside the cells of liver, spleen, lymph glands, and bone marrow.

5. ***Leishmania tropica***. It causes **skin Leishmaniasis (Cutaneous Oriental Sore)**. The infected persons may be seen with cutaneous sores on hands, feet, and face. It leads to ulcerated wounds with raised edges. The disease is spread by sand flies. The parasite lives in the endothelial cells of skin capillaries.

6. ***Leishmanian brasilliensis***. It causes **mucocutaneous Leishmaniasis** (also called **Espundia**). Espundia is characterized by lesions upon skin and mucous membrane of nose, mouth, pharynx and rarely vagina. The parasite is transmitted by the sand flies.

7. ***Giardia intestinalis*** (*Giardia lambia*). It is named *Giardia* after Professor **Giard** of Paris and *lambia* after **Lambl** of Prague who gave a detailed description of the parasite. Giardia is commonly nick named as the **"Grand Old Man of Intestine"**. It occurs in the upper part of human small intestine. Transmission occurs by taking cysts of the parasite with food and water. There are two nuclei and four pairs (one anterior and three posterior) of backwardly directed flagella. Two supporting needle-like **auxostyles** are also present. It causes epigastric pain, abdominal discomfort, diarrhoea, headache and sometimes fever. The disease caused by *Giardia* is popularly known as **giardiasis.**

8. ***Trichomonas vaginalis***. It inhabits vagina of women and causes the disease **leucorrhoea**. The disease is characterised by burning sensation, itching and frothy discharge. Transmission is by coition (sexual intercourse). In males infection of urethra and prostate is common.

9. ***Trichomonas hominis*** resides in the large intestine and causes mild diarrhoea.

10. ***Trichonympha campanula***. This zooflagellate occurs as a symbiont in the intestine of termites. *Trichonympha* secretes cellulose digesting enzymes **b-glucosidases** which convert cellulose into glucose. The digested food is shared by the zoofalgellates and termite. Without *Trichonympha* the termites starve and die.

* Named after its discoverers, Sir William Leishman and Donovan.

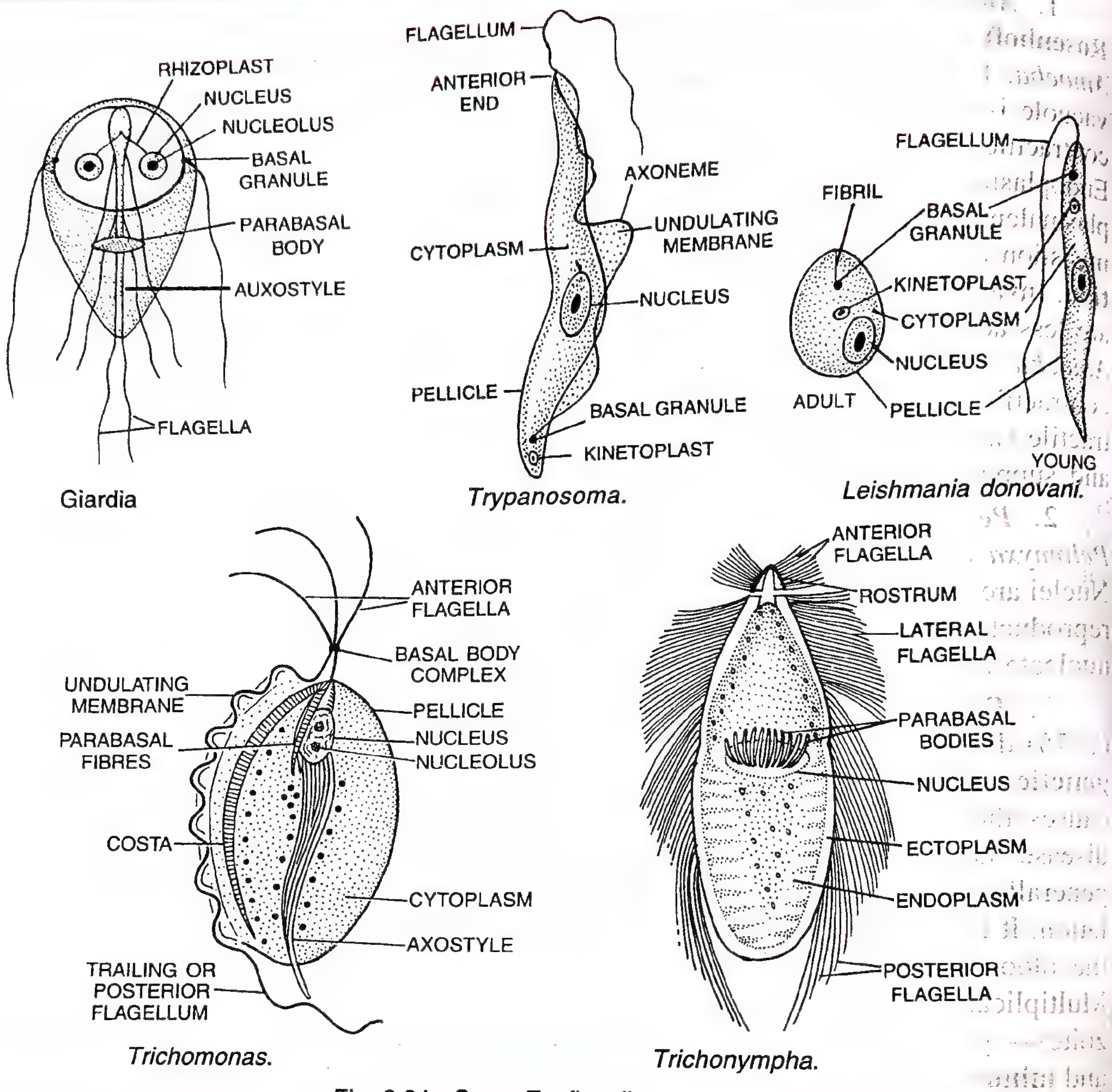


Fig. 2.34. Some Zooflagellates.

11. ***Lophomonas blattarum.*** It occurs as a symbiont in the intestine of wood roaches. *Lophomonas* secretes enzymes for digestion of cellulose. The digested food is shared by both.

Group 2. Amoeboid Protozoans

Characters. (i) They develop pseudopodia which are temporary protoplasmic outgrowths. They are of four types— **lobopodia** (broad and blunt), **filopodia** (slender, unsupported, independent), **axopodia** (slender with axial support) and **reticulopodia** (slender, reticulate). (ii) Pseudopodia are used for locomotion and engulfing food articles. (iii) Sarcodines are mostly free living, found in fresh water, sea water and on damp soil. Only a few are parasitic. (iv) The body may be covered with plasmalemma or a shell. (v) Nutrition is commonly holozoic. (vi) Sarcodines are generally uninucleate. Binucleate (*e.g., Arcella*) and multinucleate (*e.g., Pelomyxa*) types also occur but the nuclei are monomorphic. (vii) Asexual reproduction takes place by binary fission, multiple fission, budding and spores. (vii) Sexual reproduction occurs through syngamy.

Examples. *Amoeba, Pelomyxa, Entamoeba,* Radiolarians, Foraminiferans, Heliozoans.

1. ***Amoeba proteus*–The Proteus Animalcule**. Amoeba was discovered by **Russel von Rosenhoff** in 1755. **H.I. Hirschfied** (1962) has given a detailed account of the biology of *Amoeba*. It is found in fresh water. Types of pseudopodia are **lobopodia**. A contractile vacuole is present for osmoregulation. Mitochondria are often seen aggregated around the contractile vacuole of *Amoeba*. Cytoplasm is differentiated into endosperm and ectoplasm. Endoplasm is further differentiated into **plasmagel** and **plasmasol**. The body is covered by plasmalemma. Nutrition is **holozoic**. Sexual reproduction is not known. Four methods of ingestion are present in *Amoeba*. (i) **Import**. This is passive food-ingestion. (ii) **Invagination**. Invagination tube is formed to take food particles. (iii) **Circumfluence**. Food particles are less active. (iv) **Circumvallation.** Prey is very active. The contents of food vacuole in *Amoeba* first become acidic then alkaline. If an *Amoeba* is placed in distilled water, its contractile vacuole works faster. If a fresh water *Amoeba* is placed in salt water, its contractile vacuole will disappear. Sol-gel theory of amoeboid movement was given by **Hyman**, and supported by **Pantin** and **Mast**.

2. ***Pelomyxa.*** It is also known as **giant amoeba**. The size is about 2.5 mm long. *Pelomyxa* occurs in fresh water. Nutrition is holozoic. The chief food article is diatoms. Nuclei are 100–1000 in number. Both noncontractile and contractile vacuoles occur. Asexual reproduction occurs by fission. Sexual reproduction takes place by the formation of uninucleate internal gametes.

3. ***Entamoeba histolytica.*** **Lamble** (1859) discovered *Entamoeba histolytica*. **Losch** (1875) discovered its pathogenic nature. The life cycle of *Entamoeba histolytica* is **monogenetic** (single host life cycle). It resides in the upper part of the human large intestine and causes the disease known as **amoebic dysentery** or **amoebiasis.** The symptoms of the disease are abdominal pain, repeated motions with blood and mucus. The parasite is with generally one pseudopodium. Contractile vacuole is absent as there is no need of osmoregulation. It feeds on red blood corpuscles by damaging the wall of large intestine and reaching the blood capillaries. It produces ulcers. The parasite can also reach other body organs. Multiplication is by binary fission. *Entamoeba histolytica* has two forms, **magna** (trophozoite)— pathogenic form found in the mucosa and submucosa of intestine forming ulcers and **minuta**— nonpathogenic form found in the lumen of the intestine. Minuta form encysts. A mature cyst is called **tetra-nucleate cyst**. It has four nuclei and two **chromatoid bodies.** Tetranucleate cyst is the infective stage. It is important to note that only one young amoeba with four nuclei hatches out from a cyst of *E.histolytica.* However, single cyst of *E. histolytica* produces eight amoebae.

Most effective medicine for amoebiasis is **Metragyl** or **Flagyl.**

4. **Radiolarians.** They are exclusively marine, free floating sarcodines having a central perforated capsule and a fine framework or skeleton of silica. The protoplasm is differentiated into intracapsular and extracapsular parts. The extracapsular part develops pseudopodia for locomotion and ingestion. Pseudopodia are fine thread like radiating strands which may be axopodia or filopodia. The intracapsular part contains nuclei, small vacuoles and reserve food that represents the reproductive part. Reproduction occurs through binary fission and swarm spores. **Examples**, *Acanthometra* and *Collozoum.*

Radiolarian ooze is the deposit of radiolarian skeleton which is put to commercial use like **diatomaceous earth** as filtering agent and abrasive (rubing).

5. **Foraminiferans.** They are bottom dwellers, marine or fresh water sarcodines which possess a calcareous shell having one or more chambers with one or more perforations.

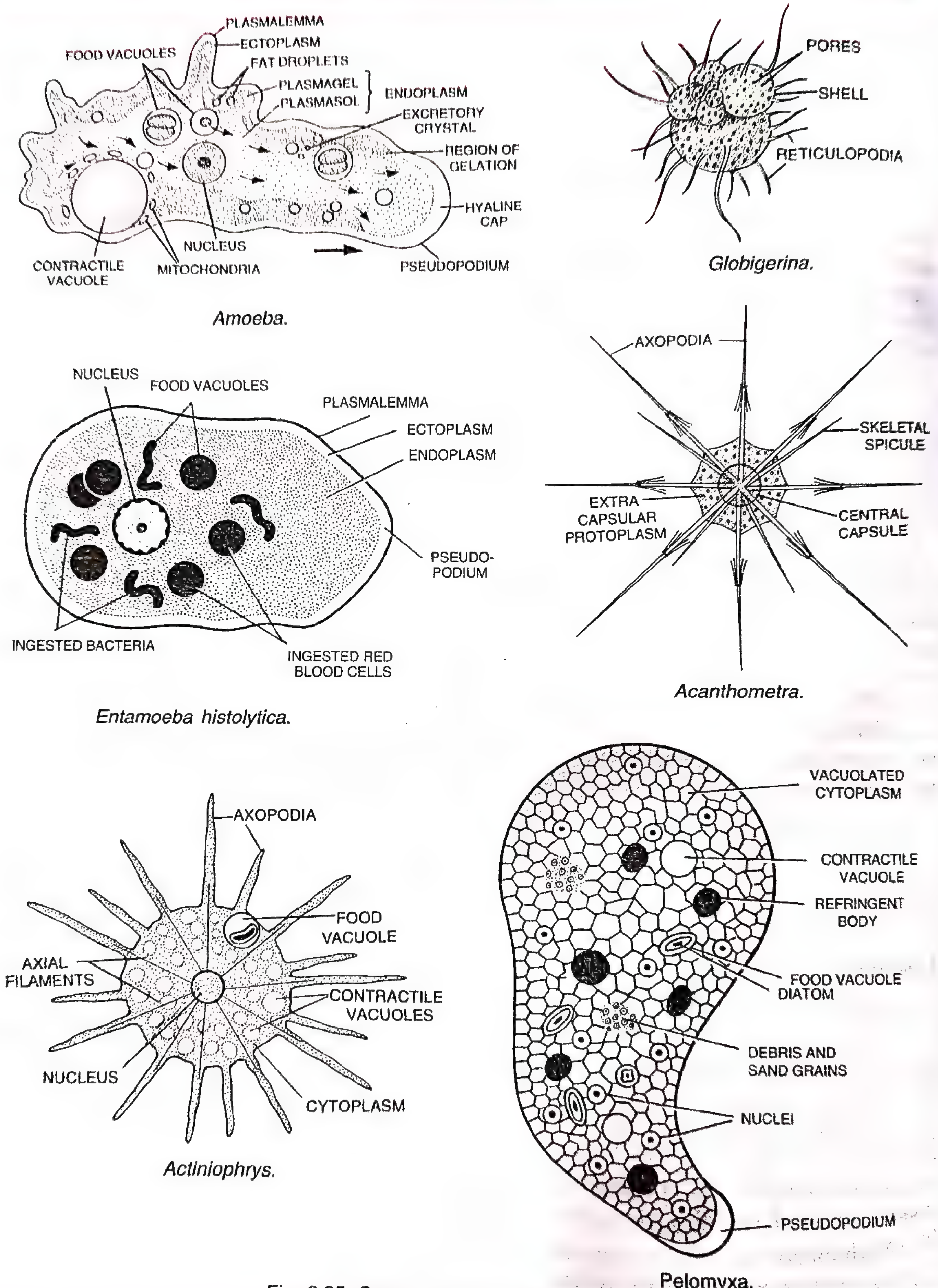


Fig. 2.35. Some Amoeboid Protozoans.

Protoplasm flows out of the pores to form a thin covering around the shell. The latter develop pseudopodia for creeping and ingestion. Pseudopodia are narrow thread like branched and anastomosing. They form a network (**reticulopodia**). Reproduction occurs by binary fission, multiple fission and flagellate gametes (syngamy). **Examples**, *Globigerina* and *Elphidium* (= *Polystomella*).

Calcerous foraminiferan shells collect at the bottom and form a **forminiferan ooze**. With time, the foraminiferan ooze changes to limestone rocks. The same are used as building material, *e.g.*, Egyptian pyramids. *Fossilised foraminiferan shells often occur in petroleum bearing formations.*

6. **Heliozoans.** They have spherical structure and were previously called **sun-animalcules**. The fine pseudopodia are called **axopodia**. The pseudopodia radiate. Heliozoans may be naked or with skeleton with siliceous scales or spines. *Actinophrys,* the **sun organism** is a common shellless heliozoan.

Group 3. Sporozoans

Characters. (i) All sporozoans are endoparasites. (ii) Some sporozoans such as *Eimeria* cause severe diseases like coccidiosis in the birds. (iii) Locomotory organelles (cilia, flagella, pseudopodia, etc.) are absent. (iv) Nutrition is parasitic (absorptive). Phagotrophy is rare. (v) The body is covered with an elastic pellicle or cuticle. (vi) Contractile vacuoles are absent. (vii) Asexual reproduction occurs through multiple fission. (viii) Sexual reproduction takes place through syngamy. (ix) Life cycle consists of two distinct asexual and sexual phases. They may be passed in one (**monogenetic**) or two different hosts (**digenetic**).

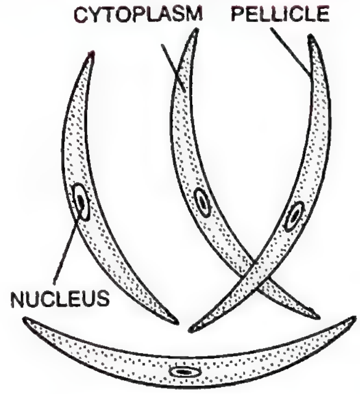


Fig. 2.36. Sporozoites of *Plasmodium vivax.*

Examples. *Plasmodium, Monocystis, Eimeria.*

Monocystis. *Monocystis* live as endoparasite in the coelomic epithelial cells and seminal vesicles of earthworm. The fertility of the earthworm is not greatly impaired, since most of the seminal vesicles are not involved.

Eimeria. *Eimeria mitis* is present as intracellular parasite in the anterior part of the ileum of adult birds. *Eimeria tenella* affects the caeca of chickens and causes a disease known as **caecal coccidiosis**. It is caused due to extensive destruction of the caecal epithelium which results in severe haemorrhage.

Plasmodium— The Malarial Parasite

Hosts. *Plasmodium* has two hosts :

(a) **Female Anopheles Mosquito**. As the sexual phase of the malarial parasite occurs in the mosquito it is considered the **definitive** (= **primary**) **host** of malarial parasite.

(b) **Human beings**. As the asexual phase of the malarial parasite occurs in man, it is considered the **intermediate** (= **secondary**) **host**.

As the female *Anopheles* mosquitoes feed on blood, only they can serve as **vector hosts** (**=carrier**) of malarial parasites. The parasite does not harm the mosquito. Male mosquitoes feed on plant sap.

Life Cycle of *Plasmodium*

Life cycle of *Plasmodium* requires two hosts (**digenetic**) for completion.

A. Life Cycle of *Plasmodium* in Man

Infection of man. The infective stage of *Plasmodium* is a minute organism called **sporozoite.** When the female *Anopheles* mosquito bites a man, sporozoites present in the salivary gland of the mosquito are injected into the blood of the man.

Pre-erythrocytic Schizogony. Cryptozoites (*crypto* = hidden) are formed.

Exoerythrocytic Schizogony. The cryptozoites enter new liver cells where they divide to form **metacryptozoites.** Exoerythrocytic schizogony is absent in *Plasmodium falciparum.*

Erythrocytic Schizogony. Metacryptozoite enters human RBC.

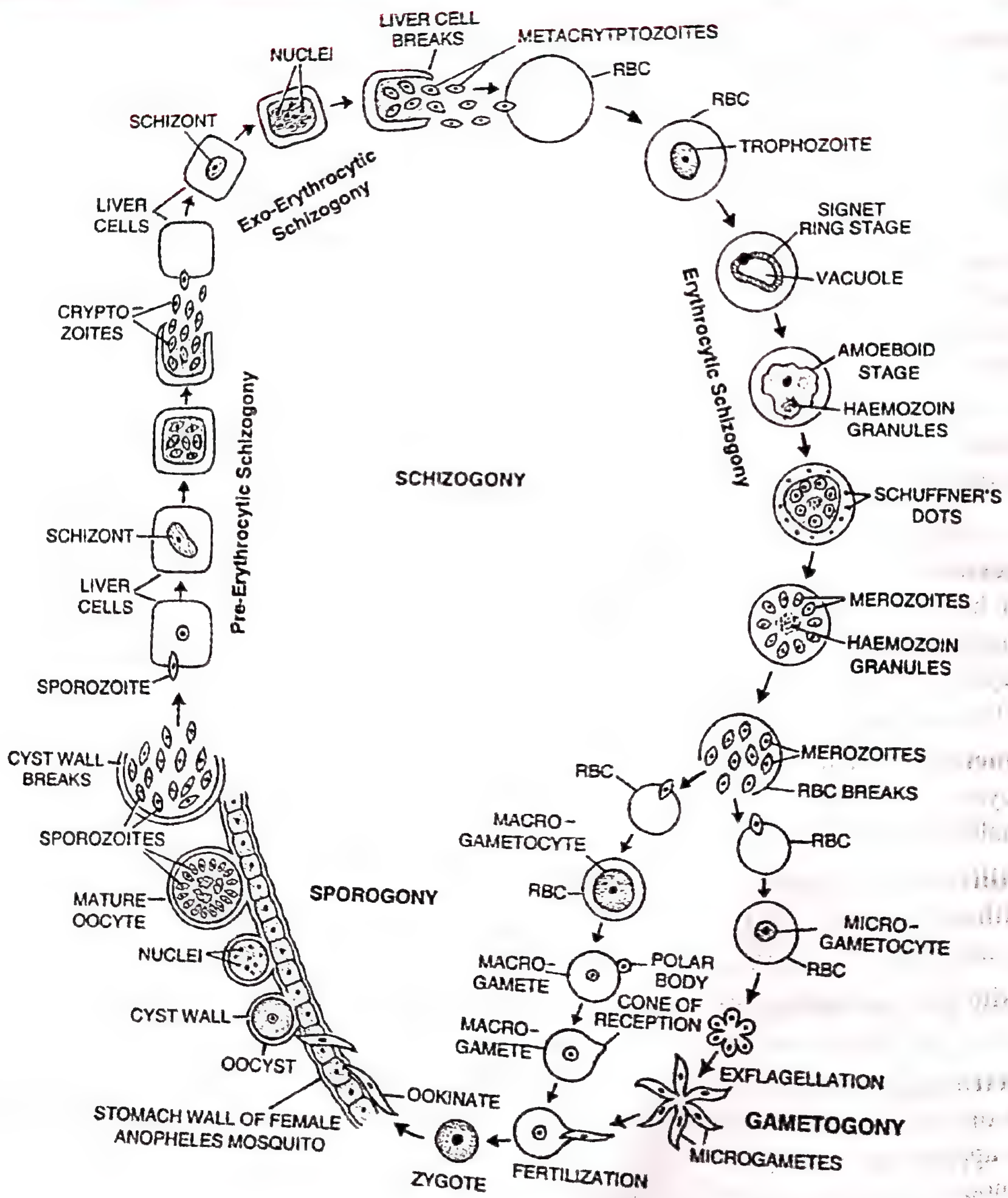


Fig. 2.37. Life cycle of Malarial Parasite.

(i) **Young Trophozoite and Signet-ring Stage.** After entering into an erythrocyte (RBC), the metacryptozoite becomes a rounded **young trophozoite.** As it grows, a large noncontractile vacuole appears in its centre, pushing the cytoplasm and nucleus to a thin peripheral layer to give a **signet-ring** appearance to the trophozoite.

(ii) **Amoeboid Stage.** The vacuole disappears and the trophozoite becomes somewhat amoeba-shaped. The trophozoite acquires brownish-black **haemozoin granules.** The haemozoin granules are infact the products of decomposition of haemoglobin derived from the cytoplasm of the erythrocytes (RBCs). Haemoglobin is broken up into **globin** (protein) and **haematin** (iron part). A number of orange or yellow granules of unknown nature, called **Schuffner's dots** (= **granules**), appear in the cytoplasm of the host RBC.

(iii) **Formation of Erythrocytic Merozoites.** The trophozoite undergoes mitotic divisions to form the **merozoites.**

Incubation period. The RBC gets ruptured to release merozoites. At this stage malaria fever is felt. The interval between the entry of the sporozoite into human blood and first appearance of the fever is called **incubation period.** It is about 14 days in *Plasmodium vivax* and *P. ovale*, 12 days in *P. falciparum*, 28 days in *P. malariae*. During this period, the parasites multiply to increase their number so that they can produce enough toxins to cause malaria.

Symptoms of Malaria. Haemozoin causes chilliness and fever. Other symptoms are muscular pains and headache. In response to chills the body temperature starts rising. The patient sweats a lot and the temperature steadily goes down to normal, till the next attack takes place after 48 hours.

(iv) **Formation of Gametocytes.** Some erythrocytic merozoites enter fresh RBCs and form rounded **gametocytes.** The gametocytes are of two types— (a) Smaller **male gametocytes** or **microgametocytes**, and (b) Larger **female gametocytes** or **macrogametocytes.**

B. Life Cycle of Plasmodium in Female Anopheles Mosquito

Ingestion by Mosquito. When a female *Anopheles* mosquito sucks the blood of an infected human host, it receives RBCs containing different stages of erythrocytic cycle, including gametocytes. In stomach of the female *Anopheles* mosquito, all stages except the gametocytes are digested. The gametocytes come out of the RBCs into the **lumen** (cavity) of the stomach of the mosquito.

Gametogony. The formation of gametes is called gametogony. The male and female gametocytes, liberated in the lumen of stomach of female *Anopheles* mosquito, form male and female gametes.

Fertilization. A microgamete penetrates a macrogamete through its **cone of reception** and **fertilization** (syngamy) takes place, resulting in the formation of a **zygote.** The syngamy is **anisogamous** as the uniting male and female gametes are dissimilar.

Ookinete. The zygote elongates and becomes worm like motile organism called **ookinete.**

Penetration and Encystment. The ookinete moves and bores through the wall of the stomach of female *Anopheles* mosquito. The encysted zygote is called **oocyst** or **sporont.** Oocysts appear upon the surface of the stomach of an infected female *Anopheles* bulging as tiny nodules. The **cyst wall** of the oocyst is partly secreted by the zygote and partly secreted by the stomach of the mosquito.

Sporogony. *The nucleus of oocyst divides first by meiosis and subsequently by mitosis*

(Bano, 1959), forming large number of small haploid nuclei. The tiny nuclei and cytoplasmic masses form elongated and spindle shaped bodies called **sporozoites.**

When mature oocysts rupture, the sporozoites are liberated into the **haemocoel** (body cavity filled with blood) of the mosquito. Being motile, the sporozoites move to different organs in the body cavity of the mosquito, but many of them penetrate the **salivary glands** of the mosquito. When the female *Anopheles* mosquito bites a healthy person, the sporozoites are injected in his/her blood along with saliva. These sporozoites start the cycle again in human body.

Control of Malaria. Malaria is widely spread disease in India. There is separate anti-malaria department of the government which controls malaria through National Malaria Eradication Programme (NMEP). Two types of measures are undertaken to control malaria: elimination of mosquitoes and their larvae and pupae and prophylaxis (prevention of infection).

1. **Elimiation of Mosquitoes and their larvae and pupae.** (i) **Destruction of adult mosquitoes.** Mosquitoes can be killed by spraying insecticides (D.D.T., flit, etc.) in the habitated areas.

(i) **Destruction of larvae and pupae of mosquitoes.** (a) Larvae and pupae can be destroyed by spraying certain chemical larvicides, such as DDT, DDD, BHC (Benzene hexachloride). (b) Ducks, larvivorous fish like *Gambusia,* some adult insects like dragon flies, insectivorous plants such as *Utricularia*, are the natural enemies of mosquito larvae and pupae as they feed upon them. These may be introduced in the water containing the larvae and pupae.

(ii) **Elimination of breeding places.** Breeding grounds of larva and pupae, such as standing waters, should be drained, so that it does not become stagnant.

2. **Prophylaxis.** (i) **Protection against mosquito bites.** Mosquito nets should be used. The exposed body parts may be protected by using mosquito repellant creams, oil, etc.

(ii) **Use of anti-malarial drugs.** The persons living in malarious regions are advised to take small regular dose of preventive medicines such as quinine, paludrine etc.

Treatment. Quinine, the oldest drug for malaria, and other drugs are also used for this purpose. Quinine is extracted from the bark of the **cinchona tree** which is mostly growing in West Indies, India, Sri Lanka, Java and Peru. Other anti-malarial drugs are **Paludrine, Primaquin, Chloroquinine, Camoquin Comoprima** and **Mepacrine.**

Group 4. Ciliated Protozoans

Characters. (i) **Kinety system** is present in ciliates which comprises cilia, **kinetosomes** (basal bodies) and **kinetodesoma** (bundle of fibrils). (ii) Cilia are used for locomotion and driving food. (iii) There is a high degree of morphological and physiological specialization. (iv) Most ciliates are free living individuals in fresh and marine waters. A few are parasites. (v) The body is covered by a pellicle. (vi) Nutrition is holozoic except in the parasitic forms. (vii) There are definite regions for ingestion and egestion. The region of ingestion consists of an oral groove, cytostome (mouth) and gullet. (viii) Ciliates show **nuclear dimorphism** or two types of nuclei, larger **macronucleus** (= meganucleus) and smaller **micronucleus.** Macronucleus controls metabolic activities and growth. It is also called vegetative nucleus. Micronucleus takes part in reproduction. Hence, it is termed as reproductive nucleus. (ix) Ciliates often possess minute ejectable **trichocysts** for defence. (x) They have contractile vacuoles for osmoregulation. (xi) Asexual reproduction takes place by transverse binary fission or

budding. Cyst formation occurs under unfavourable conditions. (xii) Sexual reproduction is by means of conjugation.

Examples. *Paramecium, Vorticella, Opalina, Balantidium.*

***Paramecium*— The Slipper Organism or Slipper Animalcule.** *Paramecium* is a free-living ciliate which is found in fresh water. Most widely distributed species are *Paramecium caudatum* and *Paramecium aurelia*. Nutrition is **microphageal.** Bacteria are its chief food. *Paramecium* is a surface feeder. **Pellicle** maintains the shape. The cilia of the extreme posterior end are longer and form a bunch called **caudal tuft.** The discharged trichocysts serve for anchoring or defence, or it may be a reaction to injury. **Feeding Apparatus** consists of **peristome** (= oral groove), **vestibule**, **buccal cavity, cytostome** (= cell mouth) and **cytopharynx.** The latter opens into the endoplasm. A temporary opening, called **cytopyge** (= **cytoproct** or **cell anus),** is present a little behind the cytostome. Undigested food is passed out through cytopyge. *Paramecium caudatum* contains a single large **macronucleus** and one small **micronucleus.** *Paramecium aurelia* has one macronucleus and two micronuclei. *Paramecium* contains two **contractile vacuoles** surrounded by 5 to 12 **radial** (feeding) **canals.** The contractile vacuoles and radial canals are for *osmoregulation.* Several non-contractile **food vacuoles** (= gastrioles) are seen moving along definite course (**cyclosis**) within the streaming endoplasm. The food vacuoles are meant for **intracellular digestion.**

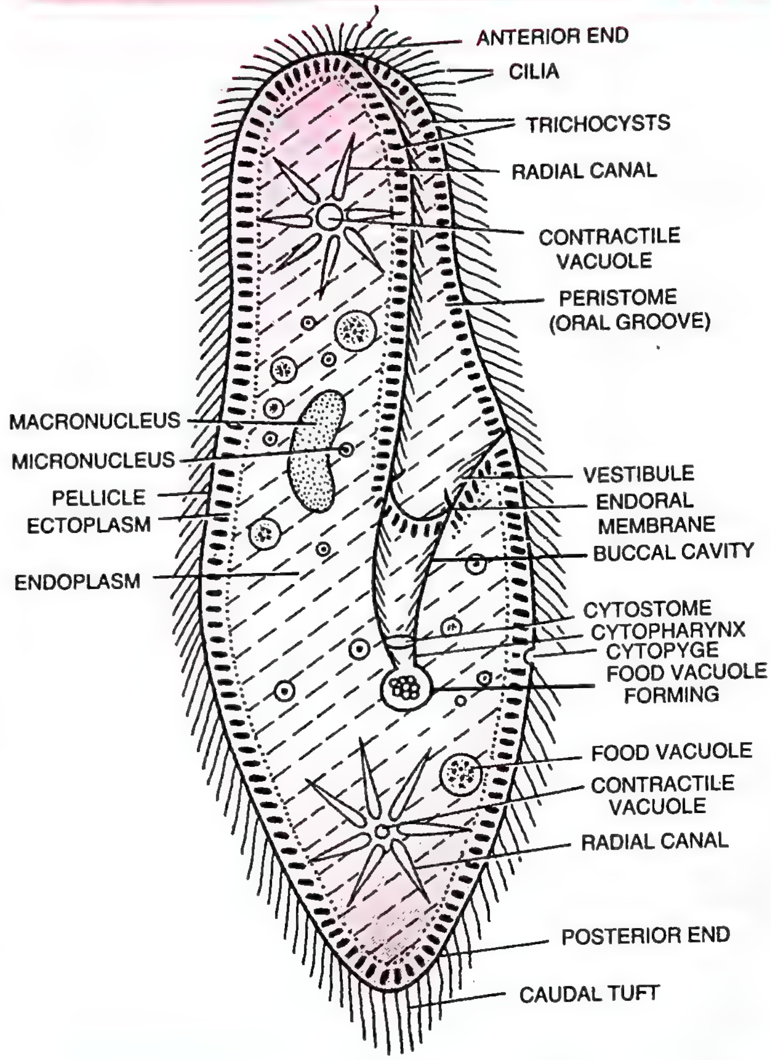


Fig. 2.38. *Paramecium caudatum.*

Both asexual and sexual reproduction are found in *Paramecium*. Asexual reproduction occurs through **transverse binary fission**. Various methods of sexual reproduction in *Paramecium* are **conjugation, autogamy** – it corresponds to self-fertilization, **endomixis** – it corresponds to parthenogenesis, **cytogamy** – it shows the characters of both conjugation and autogamy, and **hemixis** – only the macronucleus takes part in hemixis. In hemixis, the macronucleus first breaks into a few irregular pieces ; later some pieces reunite to form the macronucleus. Remaining pieces disintegrate in the endoplasm. Thus hemixis is called **"Purification Act"**.

Two types of *Paramecia* are reported :

(a) **Killer *Paramecia*** contain **Kappa particles.** The latter have DNA and RNA. Killer *Paramecium* produces a poisonous substance, called **paramecin** which kills sensitive *Paramecia.*

(b) **Sensitive Paramecia** do not contain Kappa particles and hence do not secrete paramecin.

Paramecium exhibits cytoplasmic inheritance in the occurrence of **Kappa particles.**

> According to NCERT *Chlamydomonas* and *Chlorella* (earlier placed in Algae within plants and both have cell walls) with *Paramecium* and *Amoeba* (earlier placed in Animal kingdom which are without cell wall) have been placed in Kingdom Protista. *Chlamydomonas* (flagellate and motile) and *Chlorella* (non flagellate and non motile) are unicellular eukaryotes.

Balantidium coli. This ciliate lives as an endoparasite in large intestine of human beings. It causes **ciliary dysentery** which is characterized by diarrhoea and ulceration of large intestine. The transmission of parasite is through cysts in contaminated food or water. ***Carbarsone***, ***Aureomycin*** and ***Terramycin*** are ideal medicine for curing the ciliary dysentery.

Pathogenic Protozoans of Man

Parasite	Habitat	Disease and Distribution	Mode of Transmission
1. *Trypanosoma gambiense*	Initially blood, later cerebro-spinal fluid.	Gambian sleeping sickness. Central Africa.	By bites of tse-tse fly (*Glossina palpalis*).
2. *T. rhodesiense*	Intially blood, later cerebro-spinal fluid.	Rhodesian sleeping sickness. South Eastern Africa.	By bites of tse-tse fly (*G. palpalis* and *G. morsitans*).
3. *T. cruzi*	Blood	South American trypano-somiasis (Chagas disease). Central and South America.	By contamination of wounds with faeces of triatomid bugs.
4. *Leishmania donovani*	Cells of liver, spleen, lymph-glands, WBCs, inner lining of blood capillaries and bone marrow.	Kala-azar, India	By bites of sand-fly (*Phlebotomus argentipes*)
5. *L. tropica*	Endothelial cells of skin capillaries	Cuteneous oriental sore, Persia and Arabia	By bites of sand fly (*Phlebotomus sergenti*)
6. *L. brasiliensis*	Mucous membrane of nose, mouth and pharynx.	Muco–cutaneous Leish-maniasis. Parts of Asia and Africa.	By bites of sand fly– *P. intermedius*, *P. squamipes*, *P. panamensis*.
7. *Giardia intes-tinalis*	Upper part of human small intestine.	Flagellate diarrhoea. World-wide.	By taking cysts with food and water.
8. *Trichomonas vaginalis*	Vagina	Leucorrhoea. World-wide.	By coition. (Sexual intercourse)
9. *T. hominis*	Large intestine	Mild diarrhoea. World-wide.	By taking active trophozoites deposited on food by flies.
10. *Entamoeba histolytica*	Large intestine	Amoebic dysentery World-wide	By swallowing cysts with food and drink.
11. *Plasmodium vivax*	Liver cells, red blood corpuscles	Benign tertian malaria. Most common in India.	By bites of female *Anopheles* mosquito.

12. *P. falciparum*	— do —	Maligant tertian or irregular or quotidian malaria. Common in certain parts of India.	— do —
13. *P. malariae*	— do —	Quartan malaria. Tropical countries. Less common in India.	— do —
14. *P. ovale*	— do —	Mild tertian malaria. West Africa, South America. This is the rarest of four species.	— do —
15. *Balantidium coli*	Large intestine	Ciliary dysentery. World-wide	By taking cysts with food and drink.

ADDITIONAL INFORMATION

- **Lancisi** (1717) first suspected a relationship between swamps, malaria and mosquito.
- **Laveran** (1880) discovered that malaria is caused by protozoan parasite. In fact he discovered *Plasmodium*. He got Nobel Prize in 1907.
- **Golgi** (1885) confirmed Laveran's discovery by observing stages of *Plasmodium malariae* in human RBCs.
- In 1897 **Sir Ronald Ross**, a doctor in Indian Army, established that malarial parasite is transmitted by the bite of a female *Anopheles* mosquito. In 1902, he got Nobel Prize for this discovery.
- **Grassi** (1900) described the life cycle of *Plasmodium* in the stomach of female *Anopheles* mosquito.
- **Shortt** (1948) and **Garnham** (1954) discovered the pre-erythrocytic schizogony (*Plasmodium* in human liver).
- **August 20** is celebrated as the "**Mosquito Day**" because Sir Ronald Ross established mosquito-malaria relationship on August 29, 1897.
- The cytoplasm of RBCs with trophozoite contains various pigment granules: **Schuffner's dots** in *P.vivax* and *P.ovule.* **Zeimanns's dots** in *P.malariae* and **Maurer's dots** in *P.falciparum.*
- The ruptured RBCs and schizonts referred to as "**ghost cells**", are destroyed in the spleen.
- In malaria fever the spleen enlarges. Enlarged spleen releases a lylic substance, **lysolecithin**, which further destroys RBCs. Malarial fever causes anaemia. **Jaundice** commonly occurs. An important effect of *Plasmodium falciparum* infection is excretion of haemoglobin in urine, called "**Blackwater fever**".
- Completion of an erythrocytic cycle in a fixed time of 48 to 72 hours according to different species of *Plasmodium*, indicates operation of some sort of a "**Biological Clock**".
- The Ministry of Health, Government of India started a **National Malaria Eradication Programme** (NMEP) in the year 1953.
- **Malaria Day**—20th August
- Vector Control Research Centre is located at Pondicherry.
- Some parasites are unable to live without their hosts, they are called **obligatory parasites**. Others can live without their hosts. These are known as **facultative parasites.**
- The kinetosomes and kinetodesma form the **infraciliary system** which controls the beating of cilia.
- Sonneborn (1937) discovered **Kappa particles.**
- Shelled protozoans are *Arcella*, *Difflugia*, *Elphidium* and foraminiferans.

NCERT TEXT BOOK QUESTIONS WITH ANSWERS

1. What is the nature of cels walls in diatoms ?
   ✔ The cell wall in diatoms is impregnated with silica which makes characteristic patterns on the cell. The cell wall consists of two overlapping halves like a soap-case, called upper epitheca and lower hypotheca. The cell wall is almost indestructible and forms diatomaceous earth.
2. Find out what do the terms 'algal bloom' and 'red tides' signify.
   ✔ **Algal bloom** refers to the excess growth of algae especially blue green algae, in polluted waters. **Red tide** refers to the red colour imparted to the sea water by the rapid multiplication of dinoflagellates like *Gonyaulax*.
3. Describe briefly the four major groups of protozoa.
   ✔ (i) **Amoeboid protozoans.** They move and capture their prey by pseudopodia as in *Amoeba*. Marine forms have silica shells on their surface. Some of them such as *Entamoeba* are parasites.
   (ii) **Flagellated Protozoans.** They have flagella. The parasitic form such as *Trypanosoma*, cause disease.
   (iii) **Ciliated Protozoans.** They have cilia. They also have a cavity (gullet) that opens to the outside of cell surface. Food is carried into the gullet as in *Paramecium*.
   (iv) **Sporozoans.** They have an infectious spore-like stage in their life cycle. The most important example is *Plasmodium* (malarial parasite).
4. What are the characteristic features of Euglenoids ?
   ✔ Instead of a cell wall, they have a protein rich layer called pellicle which makes their body flexible. They have two flagella, a short and a long. They are mixotrophic in nutrition as in *Euglena*, which takes its nutrition by holophytic and saprobic method. The photosynthetic pigments are similar to green algae-chlorophyll *a*, chlorophyll *b* and carotenoids.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Who proposed the term protista ?
   ✔ **Ernst Haeckel**
2. Cite an example of mixotrophic nutrition?
   ✔ *Euglena*
3. Name the transparent siliceous cell wall of Diatoms ?
   ✔ **Frustule**
4. Where does *Trypanosoma* live in humans?
   ✔ In the blood plasma.
5. Which protist causes Leucorrhoea?
   ✔ ***Trichomonas vaginalis***
6. What is digenetic life cycle?
   ✔ Life cycle of *Plasmodium* requires two hosts for completion, such a two host life cycle is called **digenetic.**
7. Who discovered *Amoeba* ?
   ✔ **Russel von Rosenhoff**

Two Mark Questions (With Sample Answers)

1. How diatomaceous earth is formed ?
   ✔ The siliceous frustules of diatoms do not decay easily. They pile up at the bottom of water reservoirs and form big heaps called **diatomite** or **diatomaceous** earth. It may extend for several hundred metres in certain areas from where the same can be mined.
2. What are the major mechanisms of locomotion found in protista? OR Name the structures which help in locomotion in protists.
   ✔ Commonly three major modes of locomotion are recognised in the protista— pseudopodial, flagellar and ciliary. Two more types are of equal importance. They are wriggling and mucilage propulsion.

3. By what characters would you separate the diatoms from the ciliates?
4. Write a brief note on cyst formation in protists.
5. Of what importance to humans are dinoflagellates and diatoms?
6. In what respect a saprobic organism differs from a parasite?
7. Write a note on sexual reproduction in protists.

Three Mark Questions (Short Answers Type)

1. What are the important characteristics of protists?
2. Describe the structure of a typical protist.
3. Describe the various modes of nutrition in protists.
4. What are the diagnostic characters of diatoms? Write the uses of diatoms.
5. Give the main characters of Dinoflagellates.
6. Name the different modes of asexual reproduction in protists.
7. Distinguish between a moneran cell from a cell of Protista.
8. Draw a well labelled diagram of *Euglena*.

Five Mark Questions (Long Answers Type)

1. What do you understand by life cycle? Describe the different kinds of life cycles found in Protista.
2. Write the diagnostic characters of (i) Slime moulds (ii) Zooflagellates (iii) Sarcodine.
3. Give an account of somatic structure and life cycle of an acellular slime mould that you have studied.
4. Write the causing agent and symptoms of (i) African sleeping sickness (ii) Kala azar (iii) Delhisore (iv) Giardiasis (v) Amoebic dysentery (vi) Malaria.

Multiple Choice Questions

(1) Thalloid body of Slime Mould is
(a) Protonema (b) Mycelium (c) Plasmodium (d) Fruiting body. *(CBSE PMT 2006)*

(2) Which of the following is monogenetic parasite ? (a) *Entamoeba histolytica* (b) *Taenia solium* (c) *Wauchereria bancrofti* (d) *Plasmodium vivax.* *(JHARKHAND CECE)*

(3) Microphagial nutrition occurs in
(a) *Amphioxus* (b) insects (c) *Paramecium* (d) *Hydra* (e) *Euglena.* *(KERALA PMT 2006)*

(4) Most appropriate words for protozoans is
(a) cellular (b) unicellular (c) acellular (d) multicellular. *(ORISSA JEE 2006)*

(5) Which species is found in South America and West Africa and is least harmful ?
(a) *P. ovale* (b) *P. vivax* (c) *P. falciparum* (d) *P. malariae.* *(ORISSA JEE 2006)*

(6) Vaccination of malaria is not possible because
(a) they produce antibodies and antitoxins. (b) they do not produce antibodies and antitoxins. (c) antibodies resistant to vaccines are produced. (d) none of the above. *(ORISSA JEE 2006)*

(7) NH_3 in amoeba is excreted by
(a) food vacuole (b) contractile vacuole (c) plasma membrane (d) all of these. *(JHARKHAND CECE)*

(8) In malaria, the product released by mosquito into blood that causes chill and fever is called
(a) haematin (b) Schuffner's dots (c) haemozoin (d) haemotoxin *(BHU 2006)*

(9) In *Amoeba*, the contractile vacuole is present (a) near the trailing end (b) near the advancing end (c) at the middle of the body (d) anywhere inside the body. *(BHU 2006)*

(10) How many young amoebae hatch out from a cyst of *E. histolytica* ?
(a) one (b) two (c) four (d) six. *(UPCPMT 2007)*

(11) Identify the alga known for a biological activity called bioluminescence
(a) *Chlorella* (b) *Spirogyra* (c) *Cyclotella* (d) *Noctiluca.* *(Karnataka CET 2008)*

(12) *Entamoeba histolytica* is transmitted through (a) insect bite (b) bird dropping (c) improperly cooked pork meat (d) food or water contaminated with cysts. *(J & K CET 2008)*

(13) Which is not true for *Paramecium* ? (a) Under unfavourable conditions, forms cysts (b) Presence of large number of cilia on whole body surface (c) Contains contractile vacuoles for osmoregulation (d) Use pseudopodia for capturing prey. *(Orissa JEE 2009)*

(14) Tonoplast is the membrane covering the
(a) mitochondria (b) vacuole (c) chloroplast (d) ribosome. *(Orissa JEE 2009)*

(15) Phylum protozoa is classified on the basis of (a) mode of reproduction (b) locomotory organelles (c) mode of nutrition (d) none of these. *(AFMC 2009)*

(16) Which of the following is not a character of protista ? (a) Protists are prokaryotic (b) Some protists have cell walls (C) Mode of nutrition is both autotrophic and heterotrophic (d) Body organization is cellular (e) Membrane bound organelles are present in cells. *(Kerala PMT 2010)*

(17) The type of nutrition present in *Entamoeba* is (a) saprozoic (b) parasitic (c) autotrophic (d) none of these *(Orissa JEE 2010)*

(18) When a fresh water protozoan is placed in marine water, ... (a) the contractile vacuoles become bigger in size (b) the number of contractile vacuoles increases (c) the contractile vacuoles disappear (d) the contractile vacuoles remain unchanged *(Karnataka CET 2010)*

(19) Where will you look for the sporozoites of the malarial parasite ? (a) Saliva of infected female *Anopheles* mosquito (b) red blood corpuscles of human suffering from malaria (c) Spleen of infected humans (d) Salivary glands of freshy moulted female *Anopheles* mosquito. *(AIPMT (Prelims) 2011)*

(20) Which one of the following organisms is not an eukaryote ? (a) *Paramecium caudatum* (b) *Escherichia coli* (c) *Euglena viridis* (d) *Amoeba proteus*. *(AIPMT (Prelims) 2011)*

(21) When a fresh water protozoan is placed in marine water (a) the contractile vacuole disappears (b) the contractile vacuole increases in size (c) a number of contractile vacuoles appear (d) the contractile vacuole remains unchanged. *(Karnataka CET 2011)*

(22) According to five kingdom classification bacteria belong to (a) protista (b) monera (c) plantae (d) archaea. *(J & K CET 2011)*

(23) In the five kingdom classification, *Chlamydomonas* and *Chlorella* have been included in (a) protista (b) algae (c) plantae (d) monera. *(CBSE Main PMT 2012)*

(24) Which one of the following sets of items in the option (a–d) are correctly categorized with one exception in it ?

	Items	Category	Exception
1.	UAA, UAG, UGA	Stop codons	UAG
2.	Kangaroo, Koala, Wombat	Australian, marsupials	Wombat
3.	*Plasmodium, Cuscuta, Trypanosoma*	Protozoan	*Cuscuta*
4.	Typhoid, pneumonia, diphtheria	Bacteria diseases	Diphtheria

(CBSE Main PMT 2012)

(25) Motile zygote of *Plasmodium* occurs in (a) salivary glands of *Anopheles* (b) human RBCs (c) human liver (d) gut of female *Anopheles*. *(CBSE PMT Prelims 2012)*

(26) Which one of the following life cycle stages of malarial parasite is responsible for relapse of malarial symptoms ? (a) Merozoite (b) Sporozoite (c) Hypnozoite (d) Gametocyte. *(West Bengal JEE 2012)*

(27) The beautiful diatoms and desmids are placed under (a) chrysophytes (b) dinoflagellates (c) euglenoids (d) slime moulds. *(AMU 2012)*

(28) Which one of the following organisms is scientifically correctly named, correctly printed according to the International Rules of Nomenclature and Correctly described ?

a) *Musca domestica* — The common house lizard, a reptile (b) *Plasmodium falciparum* — A protozoan pathogen causing the most serious type of malaria. (c) *Felis tigris* — The Indian tiger, well protected in Gir forests (d) *E. coli* — Full name *Entamoeba coli* a commonly occurring bacterium in human intestine. *(CBSE Main PMT 2012)*

(29) Which of the following human pathogens is a flagellated protozoan ? (a) Plasmodium (b) Trypanosoma (c) Taenia (d) Entamoeba. *(HP PMT 2011; Chandigarh CET 2012)*

(30) Which of the following groups of organisms have a protein rich layer called pellicle? (a) Chrysophytes (b) Euglenoids (c) Dinoflagellates (d) Slime moulds (e) Protozoans. *(Kerala PMT 2014)*

(31) The mature infective stages of malarial parasite which are transferred from mosquito to man are (a) trophozoites (b) sporozoites (c) gametocytes (d) merozoites. *(Karnataka CET 2014)*

(32) In which group of organisms the cell walls form two thin overlapping shells which fit together ? (a) Chrysophytes (b) Euglenoids (c) Dinoflagellates (d) Slime moulds. *(CBSE 2015)*

(33) Which one is not a free-living Protozoa ? (a) *Amoeba* (b) *Euglena* (c) *Giardia* (d) *Noctiluca*. *(Bihar CECE 2015)*

(34) Green phytoplanktons are kept in which kingdom of five kingdom classification system ? (a) Kingdom-Monera (b) Kingdom-Protista (c) Kingdom-Plantae (d) Kingdom-Fungi. *(Chhattisgarh PMT 2015)*

(35) Identify the characteristic features of diatoms (a) cell wall is made of cellulose, floating on water and produce auxospores (b) cell wall is made of chitin, fixed forms and produce auxospores (c) cell wall is made of silica, floating on water and produce auxospores (d) cell wall is made of silica, symbionts and produce zoospores. *(EAMCET 2015)*

(36) Kinety system is present in (a) flagellates (b) sarcodines (c) ciliates (d) sporozoans. *(EAMCET 2015)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as

(a) If both **A** and **R** are true and R is correct explanation of **A**.

(b) If both **A** and **R** are true and **R** is not correct explanation of **A**.

(c) If **A** is true and **R** is false.

(d) If both **A** and **R** are false.

1. **Assertion :** *Trichonympha* is a cellulose-digesting insect– gut zooflagellate.
   Reason : The protozoan secretes glucosidases which convert cellulose into glucose.
   A B C D
2. **Assertion :** Euglenoids change their shape.
   Reason : They have no rigid cell wall.
   A B C D
3. **Assertion :** The body of *Paramecium* is covered by a rigid cell wall.
   Reason : The cell wall is made up of cellulose.
   A B C D
4. **Assertion :** Diatom frustules pile up at the bottom of water bodies and form big heaps of diatomite or diatomaceous earth.
   Reason : Diatom frustules are resistant to natural degradation.
   A B C D
5. **Assertion :** Slime moulds are excellent material for the study of protoplasm.
   Reason : They lack cell organelles.
   A B C D

ANSWERS

Multiple Choice Answers

(1) —c (2) —a (3) —c (4) —c (5) —a (6) —b (7) —c (8) —c (9) —a (10) —a
(11) —d (12) —d (13) —d (14) —b (15) —b (16) —a (17) —b (18) —c (19) —a (20) —b
(21) —a (22) —b (23) —a (24) —c (25) —d (26) —a (27) —a (28) —b (29) —b (30) —b
(31) —b (32) —a (33) —c (34) —b (35) —c (36) —c

Assertion and Reason Types Answers

(1) —A (2) —A (3) —D (4) —A (5) —C

2C KINGDOM FUNGI

Fungi is a large kingdom of over 100,000 species. *They are achlorophyllous, heterotrophic, spore-forming, non-vascular, eucaryotic organisms which often contain chitin or fungal cellulose in their walls and possess glycogen as food reserve.* They are cosmopolitan in occurrence being present in air, water, soil, over and inside animals and plants. They are more abundant in warm and humid areas. Branch of biology dealing with the study of fungi is known as **mycology**.

Fungi have **absorptive** type of nutrition. They are either parasites or saprotrophs. **Parasites** cause diseases in animals and plants. Branch of biology dealing with fungal diseases and disease causing fungi is known as **fungal pathology.**

Saprotrophic fungi obtain their organic food requirement from dead and decaying organic matter, fruits, vegetables, meat, etc. Alongwith certain bacteria, the saprotrophic fungi function as the main **decomposers** of organic remains. They are essential for recycling of inorganic resources in the biosphere, *i.e.,* biogeochemical cycling. However, saprotrophs also spoil our food. Some fungi live as symbionts in lichens (alongwith algae) and mycorrhiza (roots of higher plants).

Important characteristics of the kingdom fungi have been listed in chapter 2 on biological classification.

Fungal Structure and Nature of Growth

Except for yeast, the body of a fungus is made of a number of elongated, tubular filaments known as **hyphae** (singular– hypha). The body of a fungus having filamentous branches or hyphae is known as **mycelium.**

In yeast, the same cell may function in vegetative growth as well as in sexual reproduction. In most other fungi there are two distinct phases, **vegetative** and **reproductive**. The vegetative phase is also called **assimilative phase**. During this phase there is rapid absorption of nutrients from the substratum. However, the fungus is seldom noticeable due to two reasons : (a) Hyaline nature of hyphae. (b) Occurrence of the major part of mycelium inside the substratum.

Reproductive phase is conspicuous in most of the fungi. The hyphae often become aerial. They form fructifications or fruiting bodies. In some cases the spores produced during this phase are coloured.

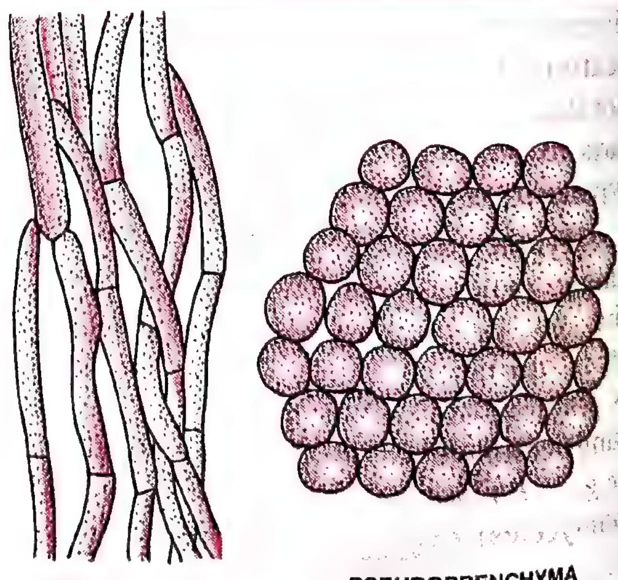


Fig. 2.39. Fungal tissues.

Tissue and Cell Structure

In several cases fungal hyphae come together

and produce a loose or compact tissue known as **plectenchyma** (Gk. *plekein*– to weave, *enchyma*– tissue). Plectenchyma is of two types, prosenchyma and pseudoparenchyma (Fig. 2.39). In **prosenchyma** (Gk. *pros*– towards, *enchyma*– tissue) the hyphae are loosely held together in parallel files. The cells are elongated and easily distinguishable from one another. In **pseudoparenchyma** (Gk. *pseudo*– false, *parenchyma*– tissue) the hyphae are closely packed. They lose their individuality and cannot be distinguishable from one another. The cells appear to be more or less isodiametric or oval. As such they resemble the cells of plant parenchyma.

The hyphae can be **aseptate** (= nonseptate) or **septate.** In aseptate hyphae cross walls or septa are not laid down at the time of nuclear division. Continued nuclear division makes the hyphae multinucleate. If the whole mycelium is without septa, the same is called **coenocytic**. In septate hyphae, cross walls or septa are laid down after the nuclear divisions. The cells may have one, two or more nuclei. Binucleate condition may develop due to plasmogamy in sexual reproduction. In that case uninucleate and binucleate conditions are respectively called **monokaryotic** and **dikaryotic**. Septa are seldom complete. They are perforated. The septa contain plasmodesmata (Powell, 1974) or central pores. In many basidiomycetes the central septal pore possesses a barrel-shaped inflation. It is known as **dolipore septum.** Simple septal pores occur in ascomycetes and deuteromycetes. They may, however, get partially plugged by membrane bounded bodies and crystalline structures called **woronin bodies.** Septal pores allow movement of substances between adjacent cells. This is useful for quick translocation of nutrients to all part of the body, mobilisation of reserve materials from older parts to younger parts and from vegetative hyphae to reproductive hyphae.

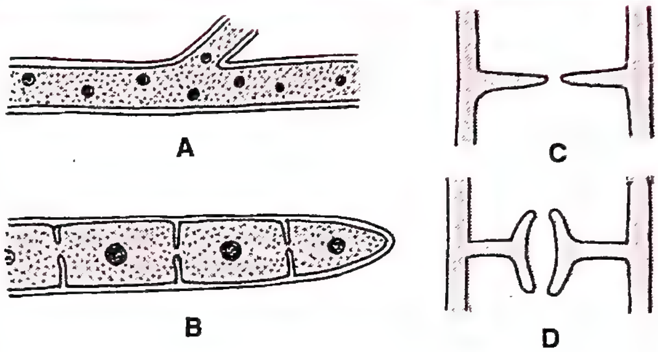


Fig. 2.40. Fungal Hyphae. A, nonseptate. B, septate C, central or septal pore. D, dolipore.

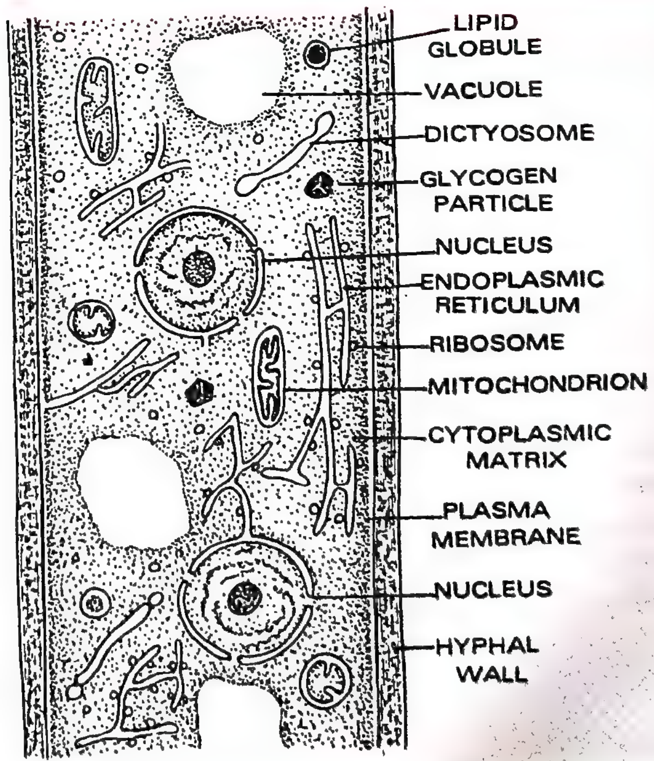


Fig. 2.41. *Rhizopus*. Part of hypha showing detailed structure as seen under electron microscope.

Hyphal or cell wall contains **chitin** or fungus cellulose alongwith other polysaccharides, proteins, lipids and a number of other substances. Fungal cellulose or chitin is polymer of acetyl glucosamine. In some fungi cellulose is also present, either alone (*e.g.*, *Phytophthora* and many other oomycetes) or alongwith chitin.

Fungal cells have eucaryotic structure. Plastids are, however, absent. A membranous vesicle called **lomasome** is found attached to plasma membrane. Endoplasmic reticulum, vacuoles, mitochondria, ribosomes,

microbodies, microtubules, etc. are typical. Dictyosomes are **unicisternal**. Food reserve is in the form of **glycogen** and oil. Special vesicles having wall materials occur near hyphal tips. They are called **chitosomes**. Nuclei are small as compared to other eucaryotes.

Reproduction

Reproduction is of three types— sexual, vegetative and asexual.

Sexual Reproduction. In involves the formation and union of two gametes or their nuclei. Sexual reproduction is absent in the artificial group of fungi called **fungi imperfecti** or **deuteromycetes**. Depending upon the compatibility in sexual reproduction, fungi are of two types— **homothallic** and **heterothallic**. In heterothallic forms sexual reproduction involves fusion between two genetically different mating types. In homothallic forms fusion occurs between genetically similar types. Fusion involves the union of cytoplasms as well as nuclei. The former is called **plasmogamy** while the latter is called **karyogamy**. In higher fungi, kayrogamy is delayed and occurs just before meiosis. In the stage intervening between plasmogamy and karyogamy the cells often contain two nuclei or **dikaryons** (n + n). Such cells are called **dikaryotic cells**. The phase is known as **dikaryophase**. In such fungi, the life cycle is completed in three phases instead of two— haplophase, dikaryophase and diplophase (2n). Meiosis occurs in diplophase. Fungi show **progressive reduction in sexuality**. Sexual reproduction occurs by five methods—

(i) **Planogametic Copulation**. Flagellate gametes differentiate and fuse. Fusion may be isogamous or heterogamous. Heterogamous fusion may be by anisogamy (gametes different in size and structure) or oogamy. In oogamy, the male gamete is generally small and flagellate while the female gamete is large, food laden and nonflagellate.

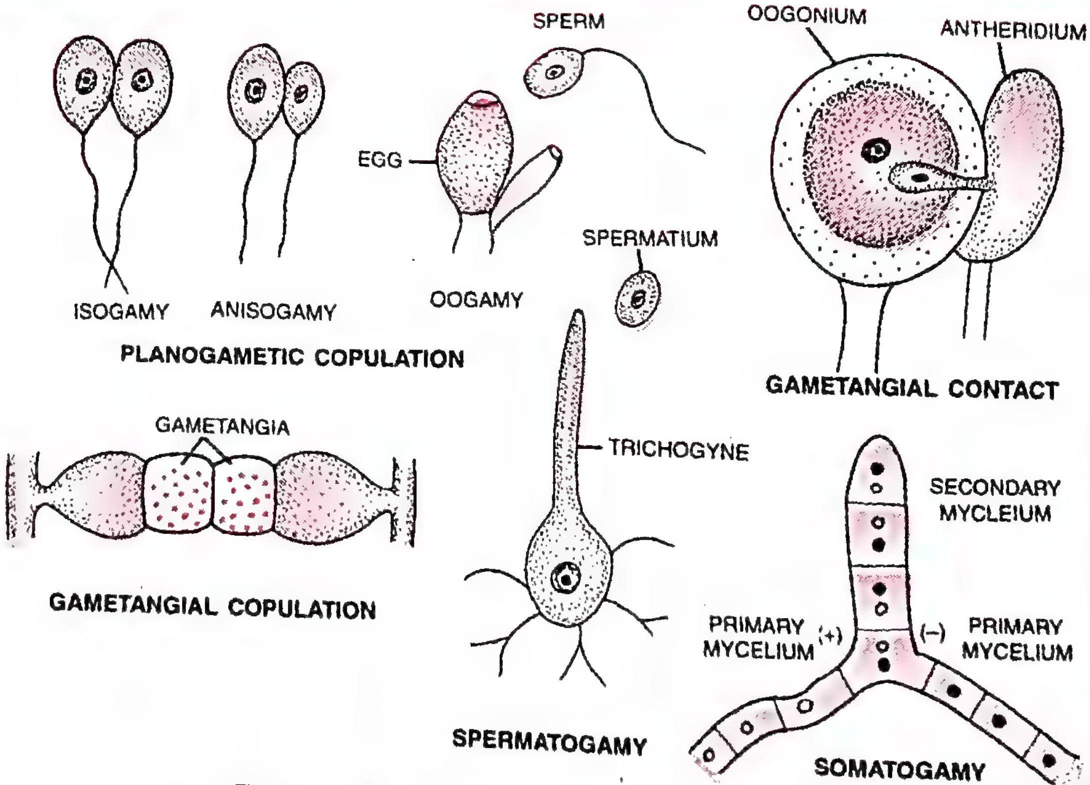


Fig. 2.42. Types of sexual reproduction in fungi.

(ii) **Gametangial Contact**. There are two types of sex organs, male **antheridia** and female **oogonia**. Male gametes or nuclei are transferred to the oogonium through a fertilization tube.

(iii) **Gametangial Copulation**. It is a type of **conjugation** in which both the types of gametangia fuse directly resulting in the formation of a zygospore.

(iv) **Spermatogamy**. Here a small male cell or gamete is carried to the receptive region or trichogyne of the female sex organ.

(v) **Somatogamy**. Distinct sex organs are absent. Sexual reproduction involves the fusion of two hyphae or cells.

Heterothallism. The phenomenon of having two genetically different and compatible sexual strains in separate thalli is known as heterothallism. It was discovered by Blakeslee in 1904. Blakeslee (1903) grew spore cultures of different mucorales. He observed that only some species were able to perform sexual reproduction in mycelia grown from single spores. The mycelium (or thallus) of these species behaved like hermaphrodite organisms in producing both the gametes taking part in fusion. He named these species as **homothallic** (*e.g.*, *Rhizopus sexualis*). Blakeslee then grew new culture of species which did not undergo sexual reproduction, *e.g.*, *Rhizopus stolonifer, Mucor caninus* (= *M. mucedo*). This time he took a number of spores from different mycelia and grew them in the same dish. To his astonishment, zygospores were formed between some mycelia and not between others. Blakeslee (1904) concluded that these species are **heterothallic**, *i.e.*, they possess two types of thalli which give rise to inherently different types of sex organs. There is no morphological difference either in thalli or their sex organs. The difference is only genetic and physiological. Therefore, the two sexual strains or mating types are termed as (+), and (–).

Vegetative Reproduction. It occurs by fragmentation, budding, fission, sclerotia and rhizomorphs. **Sclerotia** are perennating bodies made up of compact masses of hyphae. They grow under favourable conditions to produce new mycelia, *e.g.*, *Claviceps*. **Rhizomorphs** are rope-like twisted subterranean masses of hyphae with well defined apical growing point. They pass the unfavourable periods in dormant stage. Under favourable conditions each rhizomorph gives rise to a new mycelium.

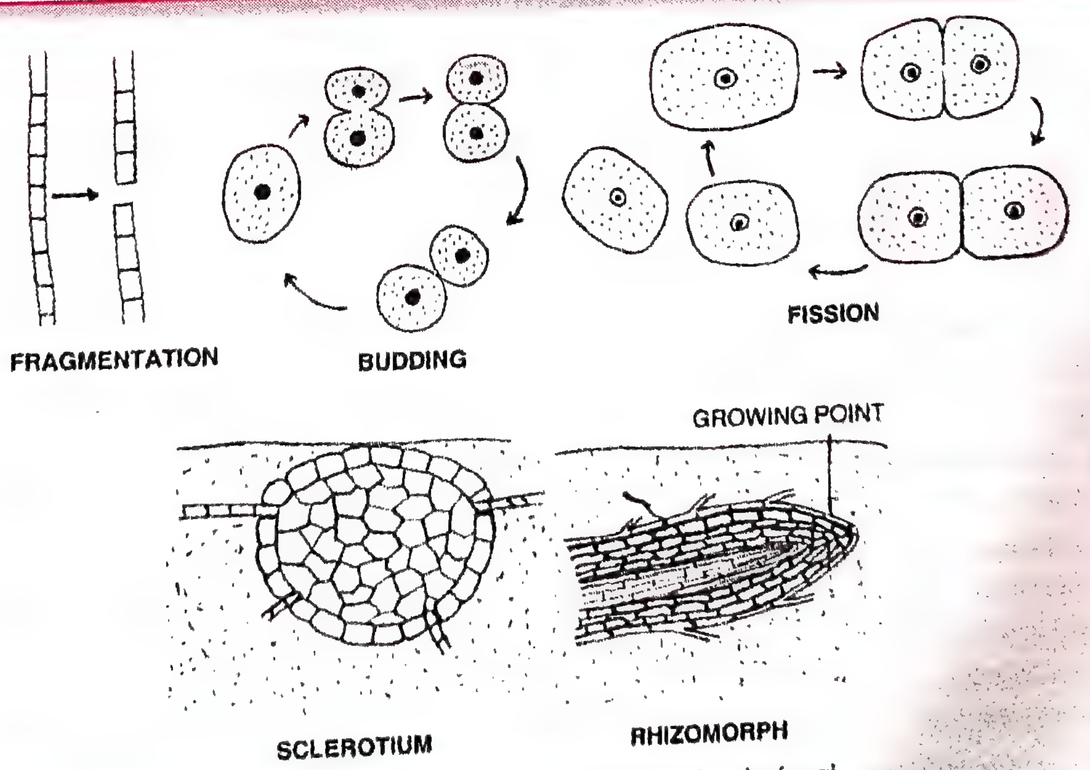


Fig. 2.43. Modes of vegetative reproduction in fungi.

Asexual Reproduction. It occurs through the formation of **spores**. Spores are single-celled propagules which separate from the parent organism and can get dispersed. They may be motile or nonmotile, naked, thin-walled or thick-walled. Some spores are produced after meiosis. They are called **sexually produced spores** or **meiospores**, *e.g.*, ascospores, basidiospores. Other spores are called **mitospores** or **asexually produced spores**. They resemble the parent body in having the same sets of chromosomes or genomes, *e.g.*, zoospores, sporangiospores, chlamydospores, oidia, conidia, etc.

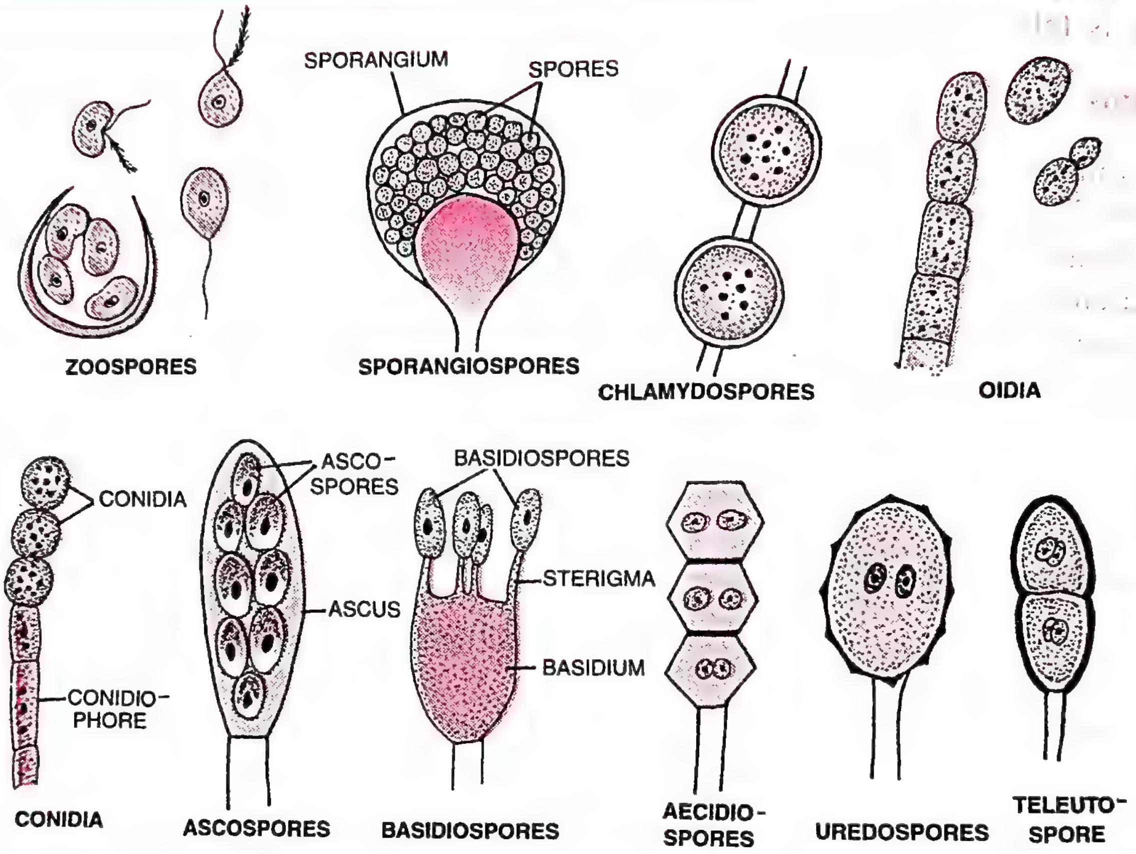


Fig. 2.44. Types of fungal spores.

1. **Zoospores.** They are motile spores that occur in some phycomycetes, *e.g.*, *Phytophthora, Albugo, Achlya.* The spores are commonly naked. 1–2 flagella are borne anteriorly, posteriorly or laterally. Flagella help the zoospores to swim in aquatic habitat for proper dispersal.

2. **Sporangiospores.** They are nonflagellate spores that develop inside sporangia, *e.g.*, *Mucor, Rhizopus.* Sporangiospores are usually dispersed by air currents. Therefore, they are produced in large numbers.

3. **Chlamydospores.** They are thick-walled perennating spores which develop at places along the hyphae by accumulation of protoplasm, rounding off and secretion of thick wall.

4. **Oidia.** They are formed under conditions of excess water, sugar and certain salts. Oidia are individual cells separated from hyphae. They multiply by budding. Oidia often take part in fermentation, *e.g.*, *Rhizopus.*

5. **Conidia.** They are nonmotile exogenous spores which develop through abstriction at the tips or sides of special hyphae called conidiophores, *e.g.*, *Pencillium, Aspergillus.*

6. **Ascospores.** They are a type of nonmotile meiospores which are produced inside

special sacs called asci (singular– ascus). An ascus often contains 8 ascospores because meiosis is accompanied by one mitosis. Ascospore formation is characteristic of class ascomycetes.

7. **Basidiospores.** Basidiospores are nonmotile meiospores which are formed exogenously on short outgrowths of club-shaped structure called basidium. Basidiospores are characteristic of basidiomycetes.

8. **Binucleate Spores.** The spores are meant for multiplying the dikaryotic mycelium. They are, therefore, themselves dikaryotic, *e.g.*, **aecidiospores, uredospores**. Both these types of spores are found in rusts, *e.g.*, *Puccinia* or Wheat Rust. Another type of dikaryotic spore is **teleutospore** or **teliospore.** It is specialized to produce a basidium.

Fungus Classification

A number of criteria are used for classifying fungi. The important ones are (a) Morphology or form structure and appearance of fungus. Morphology of assimilative (vegetative) mycelium is useful in only a few cases. Morphology of reproductive structures exhibits more variations and is hence important in fungus classification. (b) Types of spores and their dispersal. (c) Life cycle. (d) Physiology. (e) Biochemisry. The major groups of fungi are follows:

Kingdom Fungi

- Sexual Reproduction not known
  - Fungi Imperfecti or Deuteromycota
- Sexual Reproduction known
  - Mycelium Aseptate Phycomycota (lower or algal fungi)
    - Oomycetes (Oogamous fungi)
    - Zygomycetes (Conjugation fungi)
  - Mycelium Septate Eumycota (Higher fungi)
    - Ascomycetes (Sac Fungi)
    - Basidiomycetes (Club Fungi)

PHYCOMYCOTA OR PHYCOMYCETES— Lower or Algal Fungi

The Fungi are characterised by aseptate coenocytic hyphae. Asexual reproduction occurs by zoospores or aplanospores produced endogenously inside sporangia. Sexual reproduction is isogamous or heterogamous. Heterogamous reproduction is of two types, anisogamous and oogamous. Phycomycota or phycomycetes is divisible into two groups, oomycetes and zygomycetes.

OOMYCETES— The Oogamous Fungi

1. The mycelium is **coenocytic** (multinucleate and aseptate).

2. Hyphal wall contains cellulose and other glucans in many members. In some cases chitin or fungus cellulose is also present.

3. Asexual reproduction involves the formation of spore containing sacs or **sporangia.** In aquatic conditions the sporangia produce zoospores. In terrestrial conditions the sporangia often behave as spores, equivalent to conidia. Because of it, the sporangia are often called conidiosporangia.

4. Zoospores are generally biflagellate with **heterokont flagellation** in which one flagellum is **smooth** while the other is of **tinsel type** (having fine surface outgrowths called mastigonemes).

5. Gametes are usually nonflagellate.

6. Sexual reproduction is by **gametangial contact** in which the male sex organs or **antheridium** passes its product into the female sex organ or **oogonium** through a fertilization tube.

7. The product of sexual reproduction is **oospore.**

Examples

1. **Late Blight.** *Phytophthora infestans* causes late blight of Potato and occasionally of Tomato as well. Blight is the appearance of brownish to black dead areas. They are first formed on the margins and tips of leaflets. Later on the whole foliage becomes blighted. Tuber yield is reduced. The surface of the tubers also shows blighting. **Irish famine** of 1845–1847 was caused by late blight of Potato.

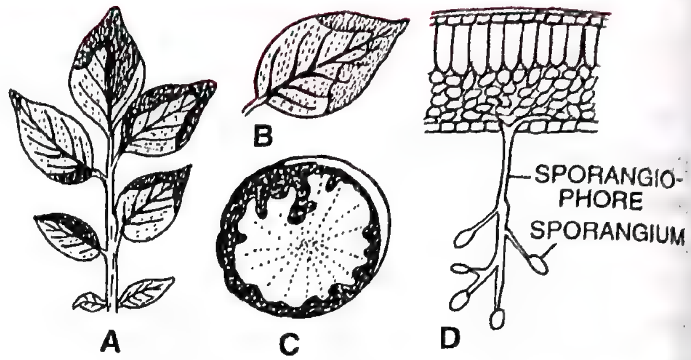


Fig. 2.45. *Phytophthora infestans*— Late blight of Potato. A, infected leaf. B, infected leaflet. C, section of infected tuber. D, sporangiophore coming out of leaflet.

2. **White Rust.** It occurs in crucifers and is characterised by the appearance of irregular white blisters containing conidiosporangia on the leaves and stems. White rust is caused by *Albugo candida* (= *Cystopus candidus*; Fig. 2.46).

3. **Damping off.** *Pythium debaryanum* kills seedlings of a number of plants through collapse of stem just above the ground level.

4. **Downy Mildew.** The pathogen produces a cottony or wooly bloom on the surface of the host. *Sclerospora graminicola* spreads downy mildew in cereals and green ear disease of *Pennisetum typhoides* (vern. Bajra). *Peronospora parasitica* causes downy mildew in a number of plants, *e.g.*, Pea, Mustard, Spinach, Onion, etc.

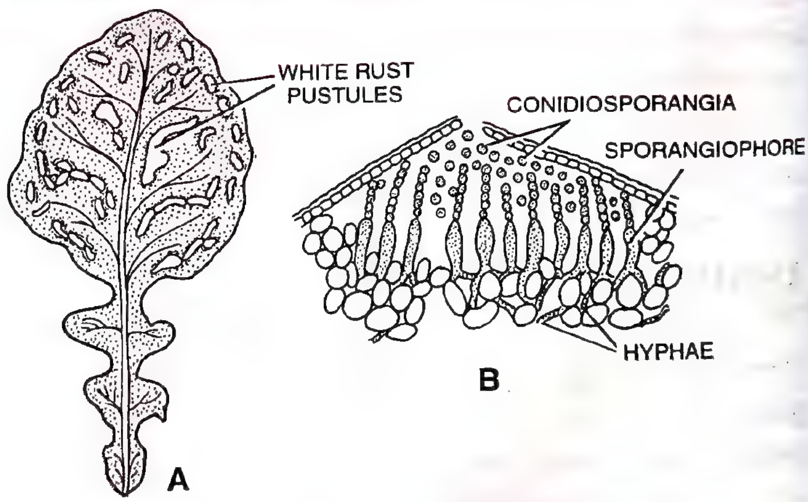


Fig. 2.46. *Albugo candida* (*Cystopus candidus*)— White Rust. A, infected leaf; B, T.S. infected leaf.

ZYGOMYCETES— The Conjugation Fungi

1. It is a class of terrestrial fungi which are mostly saprotrophic, rarely parasitic.
2. The mycelium is **coenocytic** (multinucleate, aseptate).
3. Hyphal wall contains **chitin** or fungus cellulose.
4. Motile cells (zoospores and planogametes) are absent.
5. Mitospores are nonmotile. They are called **sporangiospores** as the spores are formed inside **sporangia** borne at the tips of special hyphae called **sporangiophores**.

6. Sexual reproduction occurs through **gametangial copulation** or **conjugation**. Because of it, zygomycetes are also called **conjugation fungi**.

7. The gametes are multinucleate and are called **coenogametes**.

8. Sexual reproduction produces a resting diploid spore called **zygospore.** Because of the presence of zygospore, the group of fungi is called zygomycetes. Zygospore differs from oospore in that during its formation a distinct large food laden nonmotile female gamete is not produced.

9. Zygospore does not give rise to new mycelium directly. Instead it produces a new sporangium called **germ sporangium** (previously called zygospo-rangium). Germ sporangium forms meiospores called **germ spores**.

Examples

1. **Squirting Fungus**. *Pilobolus crystallinus* is a coprophilous or **dung mould** in which mature sporangia are thrown away upto a distance of 2m.

2. **Rhizopus and Mucor.** *Rhizopus stolonifer* (= *R. nigricans*) is popularly known as **black bread mould**. *Mucor caninus* or *M. mucedo* is **coprophilous**. It is also called **dung mould.** *Rhizopus* and *Mucor* are the common saprotrophic fungi that attack a variety of food stuffs. **Soft rot** or leak disease of Strawberry, Apple, Sweet Potato, etc. is due to *Rhizopus*. *Mucor pusillus* causes infection of internal organs in human beings. *Absidia corymbifera* causes **bronchomycosis**.

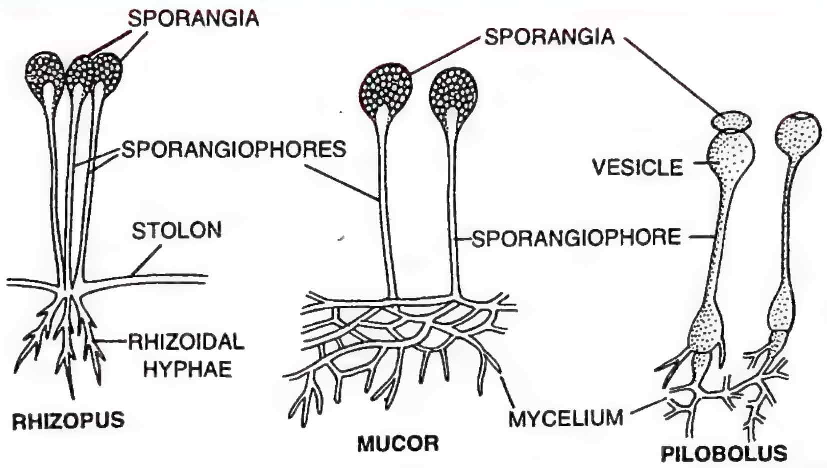


Fig. 2.47. Three common zygomycetes.

Both *Rhizopus* and *Mucor* species (*e.g., Rhizopus oryzae, Mucor javanicus*) are used in alcoholic fermentation. The two also produce a number of organic acids like citric acid, lactic acid and fumaric acid.

ASCOMYCETES— The Sac Fungi

1. Ascomycetes (Gk. *askos*– sac, *mykes*– fungus) is a class of diverse fungi numbering over 30,000 species (Ingold, 1967). They include pigmented moulds (brown, green, blue, pink), powdery mildews, yeasts, cup fungi, morels and truffles. Nutritionally they are saprotrophic, decomposers, coprophilous or parasitic.

2. The mycelium consists of **septate** hyphae. Yeasts are an exception in that they are basically unicellular. They may, however, form short temporary filamentous structure called **pseudomycelium**.

3. The septa possess central pores called **septal pores**. The pores allow communication between adjacent cells. Septal pores show plugging of different types.

4. Cell wall contains chitin or fungus cellulose.

5. Motile structures do not occur in the life cycle.

6. In yeasts, asexual reproduction occurs through budding and fission. Oidia stage, similar to yeast, is found in some other ascomycetes as well.

7. In majority of ascomycetes, the common mode of asexual reproduction is through the formation of **conidia** (singular– conidium). Conidia are nonmotile fungal **mitospores** which are produced exogenously from the tips and sides of hyphae called **conidiophores**.

Conidia are often coloured brown, green, blue or pink. They provide colouration to the fungus. Greenish and bluish growth on bread, citrus fruits and old leather is due to moulds belonging to ascomycetes *e.g., Penicillium, Aspergillus.*

8. Conidiophores may be branched or unbranched, scattered or aggregated to form structures like acervulus, synnema, sporodochium, etc.

9. Sexual reproduction takes place through fusion of sex cells, somatic cells, gametangial contact between an antheridium and ascogonium, and autogamy.

10. Fertilization occurs in two steps, plasmogamy and karyogamy. Karyogamy is delayed after plasmogamy. A new transitional phase appears in the life cycle. It is called **dikaryophase.** The cells of dikaryophase are called dikaryotic cells. Each such cell possesses two nuclei (n+n).

11. Some dikaryotic cells function as **ascus mother cells**. The latter act as the seats of both karyogamy and meiosis. This converts the cells into **asci** (singular– ascus).

12. Ascus is a sporangial sac peculiar to ascomycetes. 4–8 haploid meiospores named **ascospores** are produced internally in each ascus. In most of the cases half the number of ascospores belong to one mating type while the other half belong to the second mating type.

13. The asci may occur freely or get aggregated with dikaryotic mycelium to form fructifications called **ascocarps**. Ascocarps are of many types : cup-like (apothecium, *e.g., Peziza*), flask-shaped (perithecium *e.g., Neurospora*), elongated with a slit (hysterothecium) or closed (cleistothecium *e.g., Penicillium*). The fructifications of some ascomycetes are edible and considered delicacies, *e.g.*, morels, truffles.

Differences between Conidia and Ascospores

Conidia	*Ascospores*
1. They are accessory spores.	1. They are meiospores.
2. Conidia develop exogenously over the conidiophores.	2. Ascospores develop endogenously inside asci.
3. A conidiophore bears numerous conidia.	3. Only eight ascospores are formed in an ascus.
4. Conidia are genetically similar and of one mating type.	4. Ascospores are genetically dissimilar and of two mating types.

Examples

1. **Yeasts.** Yeasts are a group of nonmycelial or pseudomycelial ascomycetes which multiply asexually by budding or fission and where asci are not organised into ascocarps. Depending upon the mode of asexual reproduction, yeasts are of three types— budding yeasts (*e.g., Saccharomyces*), fission yeasts (*e.g., Schizosaccharomyces*) and halobial yeasts (both budding and fission, *e.g., Saccharomycoides*). Yeasts in which ascus formation is known are named as true yeasts. Related forms which resemble yeasts in most characteristics but where ascus formation is not reported, are called **false yeasts**, *e.g., Candida, Mycoderma, Cryptococcus.* They are otherwise included amongst **deuteromycetes.**

Economic Importance. (i) **Brewing Industry.** Under anaerobic conditions sugary solutions inoculated with yeasts are converted into alcoholic beverages, *e.g.*, beer, wine, cider, toddy. They are concentrated further to produce rum and whisky. The two common yeasts used by brewing industry are *Saccharomyces cerevisiae* (Beer or Baker's yeast) and *S. ellipsoidens* (Wine Yeast). (ii) **Baking Industry.** Kneaded flour is inoculated with *Saccharomyces cerevisiae* (Baker's Yeast). It produces carbon dioxide and alcohol. The two evaporate during baking, making the dough soft and spongy. (iii) **Vitaminised Food.** Yeast used in brewing industry is regularly harvested and used as vitaminised food. (iv) **Curing.** Yeasts are used in curing cocoa beans. (v) **Spoilage of Food**. Being saprotrophic, yeasts attack

various food stuffs including tomato products, foods having lactic acid and carbonated beverages. (vi) **Silk Industry.** Some yeasts reduce the yield of silk industry by attacking silkworms. (vii) **Plant Diseases.** Species of *Nematospora* attack Cotton, Tomato and Beans. (viii) **Human Diseases.** *Candida albicans* causes thrush and inflammation of genitalia. *Cryptococcus neoformans* attacks nervous system producing lesions, meningitis and brain tumour. *Torula* produces skin nodules and lesions of viscera. (ix) **Statins.** They are cholesterol lowering chemicals which are produced by fermentation activity of *Monoscus purpureus*.

2. ***Aspergillus*.** It is a common green smoky mould which not only contaminates laboratory cultures (hence **weed of laboratory**) but also various food stuffs including bread, butter, cheese, syrups, jams, jellies, textile and leather goods. It causes rotting of dates, figs, pomegranates, cigars and tobacco. Some lung (pulmonary aspergillosis) and ear infections are caused by *Aspergillus* species. Fermentation effected by *Aspergillus* yields alcohol (Sake of Japan), citric acid, gluconic acid, glycerol, B-complex vitamins, enzymes and antibiotics.

3. ***Penicillium*.** *P. chrysogenum* yields the antibiotic **penicillin**. The latter was the first commercial antibiotic. It was formerly obtained from *P. notatum*. *P. griseofulvum* produces antifungal drug **griseofulvin.** The fungus is employed in ripening of cheese (camembert and roquefort varieties) and production of organic acids. The fungus is otherwise known to spoil food, citrus fruits, apple, grape, paper, wood and ensilage. The **blue-green mould** appearing on citrus fruits is *Penicillium*.

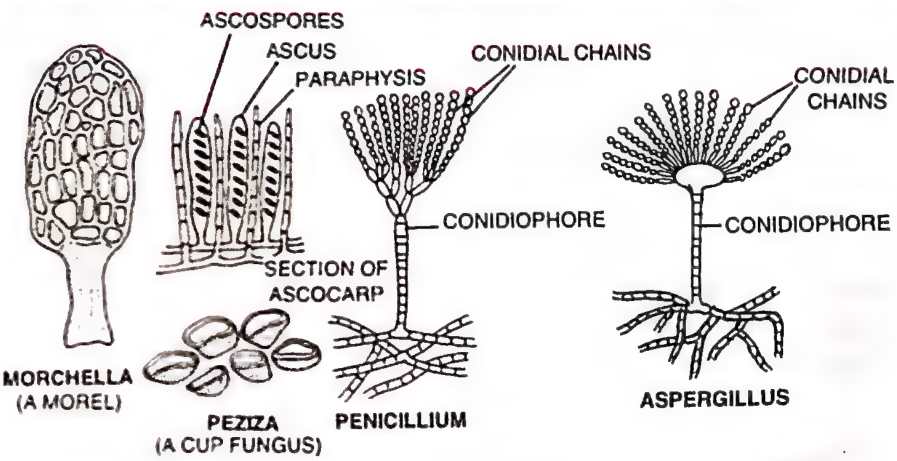


Fig. 2.48. Some ascomycetes.

4. ***Neurospora*** (Pink Bread Mould). *N. crassa* is often employed in studies conducted in experimental genetics. It is often called **"Drosophila of plant kingdom"**.

5. ***Erysiphe*.** The fungus produces **powdery mildew** (fungal disease in which pathogen results in a powdery coating on the surface of the host), *e.g.*, *Erysiphe graminicola* (*E. graminis*, on cereals like Wheat, Barley), *E. polygoni* (on legumes like Pea).

6. ***Claviceps*.** *Claviceps purpurea* produces **ergot of rye** and other cereals in which ears come to have **sclerotia** of the fungus. Eating of infected cereals produces **ergotism**. Ergotism is of two types, gangrenous and spasmodic. The sclerotia contain a number of alkaloids, the most important being **lysergic acid.** Ergot is used as a medicine to control migraine, enlarged prostate glands and uterine haemorrhage after child birth. These days lysergic acid is prepared through fermentation activity of *C. paspali*. LSD, a hallucinogen, is D-lysergic acid diethylamide-15.

7. ***Sclerotinia*.** *S. fruticola* causes brown rot of Peach, Plum and Pear.

8. **Cup Fungi.** The ascocarp is cup-shaped, *e.g.*, *Peziza*.

9. **Morels.** Morels are ascomycetes with edible ascocarps that have fleshy sponge-like conical cap or pileus and a stalk like stipe, *e.g.*, *Morchella esculenta* (vern. Gucchi), *M. crassipes, M. deliciosia*.

10. **Truffles.** They are edible ascomycetes with tuber-like subterranean ascocarps that are often dug out with the help of trained dogs and pigs, *e.g.*, *Tuber uncinatum, T. aestivum.*

BASIDIOMYCETES— The Club Fungi

1. Basidiomycetes (Gk. *basidium*– small base, *mykes*– fungus) are the most advanced and most commonly seen fungi as their fructifications are often large and conspicuous, *e.g.*, mushrooms (gill fungi), toadstools, puff balls, bracket fungi, etc.

2. The class contains about 25,000 species.

3. Basidiomycetes are among the best decomposers of wood. Only a few insects can compete with basidiomycetes in decomposing hard woods and woody structures of trees. Basidiomycetes are able to decompose both cellulose and lignin. Lignin is not metabolised by most other fungi and even bacteria. For decomposing wood, these fungi secrete cellulose and lignin digesting enzymes. The enzymes create spaces in the wood for hyphae to pass inwardly. It is because of this that we sometimes observe toadstools and mushrooms to come out of wooden structures. *Gonaderma* species causes decay of wood even of standing trees.

4. Motile structures or cells are absent.

5. Mycelia are of two types, primary and secondary. **Primary mycelium** contains **monokaryotic cells**, that is, cells with single haploid nuclei (n).

6. Monokaryotic phase or primary mycelium may multiply by oidia, conidia-like spores and pycniospores. Dikaryotic mycelium does not multiply by asexual spores.

7. There is often differentiation of two mating types, (+) and (–).

8. Sexual reproduction does not involve sex organs. Instead plasmogamy (fusion of protoplasts without fusion of their nuclei) occurs by fusion between basidiospores and other monokaryotic spores, between a spore or spermatium and a hypha or between two hyphal cells of primary mycelia.

9. Karyogamy is delayed for long. The intervening phase is called **dikaryophase**. It produces a new mycelium called **secondary mycelium** which is dikaryotic (n+n).

10. Secondary mycelium is long lived. It consists of profusely branched septate hyphae.

11. Septa possess **dolipores** or central pores with barrel-shaped outgrowths.

12. Hook-shaped outgrowths are found on the sides of septa. They are called **clamp connections**. Clamp connections are meant for proper distribution of dikaryons at the time of cell division.

13. Secondary mycelium can perennate in the soil or wood by means of **sclerotia** (often rounded or ellipsoid firm masses of hyphae) or **rhizomorphs** (root-like aggregation of hyphae with well defined apical meristems).

14. Dikaryophase or secondary mycelium may multiply by different types of spores— chlamydospores, aecidiospores, uredospores, teleutospores, etc.

15. Karyogamy and meiosis occur in club-shaped structures known as **basidia** (singular— basidium). The name of the class is based after them. A basidium may be aseptate (holobasidium) or septate vertically or transversely (phragmobasidium).

16. A basidium commonly produces four meiospores or basidiospores exogenously at the tips of fine outgrowths called sterigmata.

17. The fungi may or may not produce fructifications called **basidiocarps**. The basidiocarps vary from microscopic forms to large macroscopic structures. Some puff balls and brackets can be over 50 cm in diameter.

Differences between Ascomycetes and Basidiomycetes	
Ascomycetes	*Basidiomycetes*
1. They are sac fungi.	1. They are club fungi.
2. Septa possess simple central pores.	2. Septa have dolipores or pores with bracket-shaped outgrowths.
3. Clamp connections do not occur.	3. Clamp connections occur between adjacent cells.
4. Primary mycelium well developed.	4. Primary mycelium is less developed.
5. Sex organs are common.	5. Sex organs are absent.
6. Karyogamy and meiosis occur inside an ascus.	6. Karyogamy and meiosis occur inside a basidium.
7. Ascospores are formed exogenously.	7. Basidiospores are formed exogenously.

Examples

1. **Rusts.** They are characterised by the formation of rusty pustules containing the spores. A basidiocarp is absent. (i) *Puccinia graminis tritici* — **black rust of wheat.** (ii) *Puccinia glumarum* — **yellow rust of wheat.** (iii) *Hemileia vestatrix* — **leaf rust of coffee.**

2. **Smuts.** They produce thick-walled black-coloured resting spores called **smut spores** (= teleutospores = chlamydospores). Smuts are of two types, **covered** and **loose.** In covered smuts the spore mass remains within the host till the latter is set free, *e.g., Ustilago maydis* (**smut of corn**), *Tilletia tritici* (**bunt** or stinking smut of **wheat**). In loose smut the spores are exposed while attached to the host, *e.g., Ustilago tritici* (**loose smut of wheat**).

3. **Mushrooms.** They are edible and nonedible agaricales which possess umbrella-like basidiocarp. The edible mushrooms generally possess coloured basidiospores. Common examples are *Agaricus campestris, Agaricus brunnescens* (= *A. bisporus*), *Volvariella volvacea* (Paddy Straw Mushroom), *Lentinus edodes* (Shiitake Mushroom).

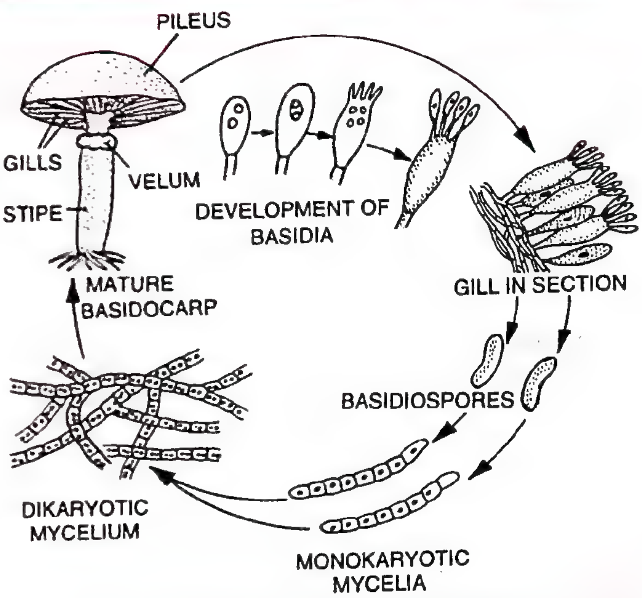


Fig. 2.49. Life history of mushroom *Agaricus campestris.*

4. **Toadstools.** Toadstools are nonedible, often poisonous mushrooms which generally have white spores. *Amanita caesarea* (Caesaer's Mushroom) was used in poisoning Roman emperor Caesar. The other toadstools are *Amanita palloides* (Death Cup) and *A. muscaria* (Fly Agaric).

5. **Bracket Fungi** (Shelf Fungi). The basidiocarps or fructifications appear on tree trunks, logs, lumber, etc. just as brackets or shelves, *e.g., Fomes applanatus* (perennial), *Polyporus sulphureus* (annual).

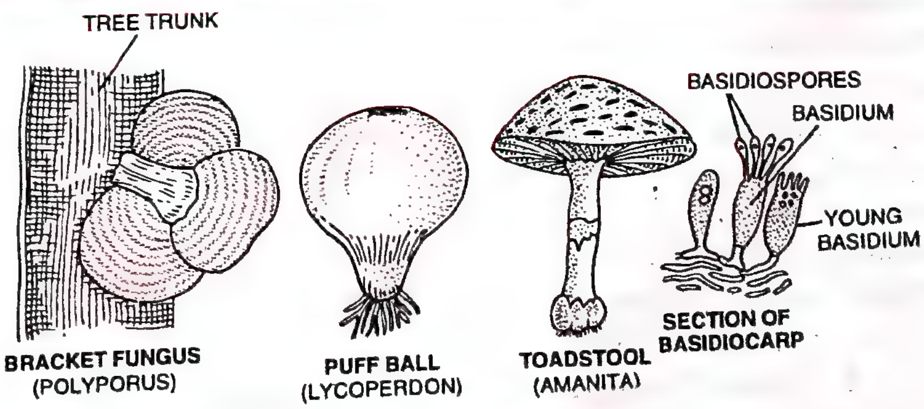


Fig. 2.50. Some basidiomycetes.

6. **Puffballs.** The basidiocarp is a stalked rounded structure which on ripening sends out puffs of spores. The fructification may grow above or below the substratum. Puffballs are odoriferous. They are edible in the young state, *e.g.*, *Lycoperdon oblongisporum*, *L. giganteum*..

7. **Armillariella** (= *Armillaria*). *A. mellea* (Honey Mushroom) is an edible mushroom which is a serious root parasite of both hardwoods and conifers. The fungus sends rhizomorphs into the phloem of the host and hence block the food supply.

8. **Hallucinogens.** *Psilocybe mexicana* (Sacred Mushroom) has hallucinating properties similar to LSD. It is used by Mexican Indians for certain religious ceremonies.

DEUTEROMYCETES— The Fungi Imperfecti

1. Deuteromycetes is an artificial class of fungi which has been created to include all those fungi in which sexual stage is either absent or not known.

2. Some of the deuteromycetes are unicellular like yeasts. They are often studied alongwith the latter.

3. The mycelium is usually septate. Coenocytic forms are not known. Clamp connections, typical of basidiomycetes, are absent.

4. Asexual reproduction often occurs by conidia alongwith some other types of spores. In some cases even asexual spores are absent.

5. It is believed that most members of deuteromycetes are actually ascomycetes in which sexual reproduction is either absent or yet to be discovered.

Examples

1 **Red Rot** (Fig. 2.51). *Colletotrichum falcatum* produces red rot of sugarcane which is conspicuous on leaf midribs as well as in canes. It reduces juice content of canes and brings about withering of leaves. The fungus develops sickle-shaped conidia. The perfect stage is *Glomerella tuccumanensis*.

2. ***Helminthosporium*** (Fig. 2.52). *Helminthosporium oryzae* causes leaf spot disease of rice commonly called **sesame** or **brown leaf spot of rice**. It caused Bengal famine of 1942–43 and similar conditions in Krishna-Godavari area in 1989–1990. The perfect stage of the fungus is *Cochilobolus miyabeanus*. The conidia are 5–10 septate.

3. **Early Blight.** *Alternaria solani* causes early blight of Potato and Tomato. The leaves develop small oval brown spots with concentric rings. The leaves as well as the branches wither and fall down. The conidia are beaked bottle-like multiseptate with a number of transverse and a few longitudinal **septa.**

4. **Tikka Disease.** Circular necrotic dark brown or blackish leaf spots develop in groundnut due to *Cercospora*

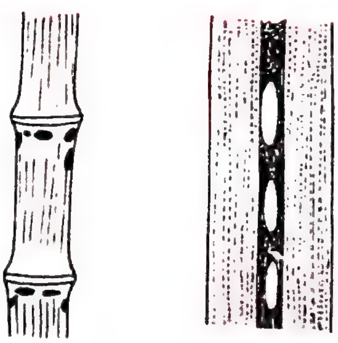


Fig. 2.51. Red rot disease of Sugarcane. A, infected cane. B, part of infected leaf.

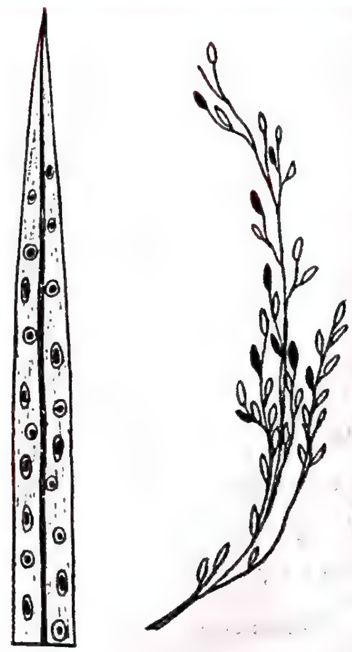


Fig. 2.52. Sesame or brown leaf spot disease of rice. A, infected leaf. B, with infected grains.

(*e.g.*, *C. personata*). The conidia are septate and filamentous. The perfect stage is *Mycosphaerella* (*e.g.*, *M. berkeleyii*).

5. **Wilts.** Many economically important plants (*e.g.*, Potato, Tomato, Cotton, Banana, Flax, Pigeon Pea) show sudden signs of wilting due to blockage of tracheary elements by growth of fungus *Fusarium* especially *F. oxysporum*. The fungus shows three types of spores — chlamydospores, microconidia and macroconidia.

6. **Gibberellins.** They were first discovered in the extracts of *Fusarium moniliformae* growing on rice (bakanae or foolish disease of rice). The perfect stage of fungus is *Gibberella fujikuroi*. Gibberellins are natural plant growth hormones.

7. ***Trichoderma*** (Fig. 2.53). It is a soil fungus used in biological control of other fungi as it produces allelochemics against them. *Trichoderma* produces chitinase and cyclosporin A. If the fungus happens to pass into human alimentary canal it produces **leucopenia** called **alimentary canal aleukia**.

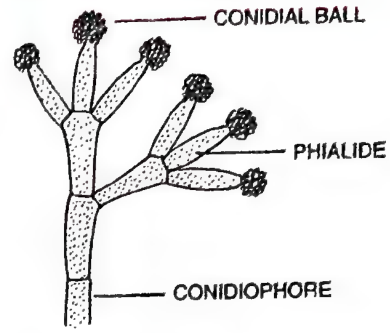


Fig. 2.53. Conidiophore of *Trichoderma*.

LICHENS (Mycophycomycetes)

Lichens are **dual organisms** or entities which contain a permanent association of a fungus or **mycobiont** and an alga or **phycobiont**. The fungal partner is usually an ascomycete and sometimes, a basidiomycete. The algal partner is mostly a green alga or a cyanobacterium (blue-green alga). The term lichen was coined by Theophrastus (370–285 B.C.). There are about 400 genera and 15,000 species of lichens. Lichens often grow in most inhospitable and uninhabited places like barren rocks, cooled volcanic lava, icy tundra or alpines, sand dunes, roofs, walls, window panes, tree bark, leaves, etc. They commonly live under humid and exposed conditions but can tolerate extreme desiccation. However, lichens cannot tolerate air pollution, especially due to sulphur dioxide.

Lichens are perennial. Their growth is slow. Some lichens of arctic region are believed to be 4500 years old. Lichens have greyish, yellowish, greenish, orange, dark brown or blackish colouration.

Structure. In shape, the lichens are of three types : (i) **Crustose.** Crust-like closely appressed to the substratum and attached to it at several places, *e.g.*, *Graphis*,

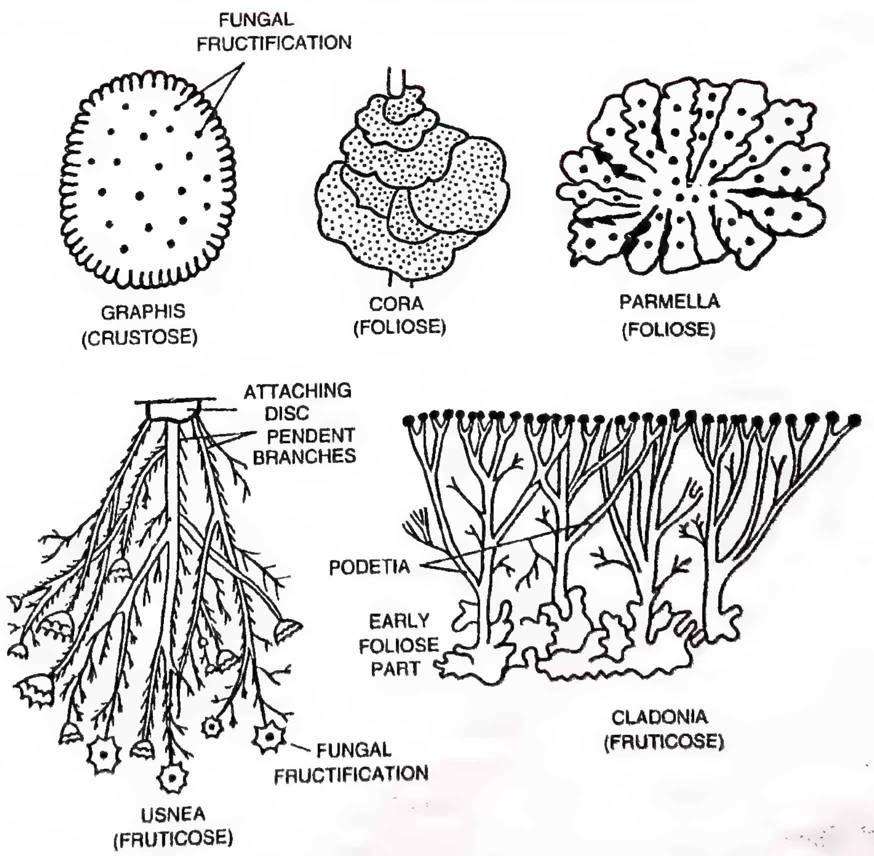


Fig. 2.54. Forms of Lichens.

Lecanora, Rhizocarpon, Haematoma. (ii) **Foliose.** The body of the lichen is flat, broad, lobed and leaf-like which is attached to the substratum at one or a few places, *e.g., Parmelia, Peltigera*. Foliose lichen *Cora (= Dictyonema) pavonia* resembles bracket fungi in appearance. (iii) **Fruticose.** The lichen is branched like a bush and attached to the substratum by means of disc, *e.g., Cladonia, Usnea, Evernia*.

The bulk of lichen body is formed by fungal partner or mycobiont. It includes the surface, medulla (or interior) and rhizines (attaching devices). The algal partner or phycobiont constitutes hardly 5% of the lichen body. It is generally restricted to a narrow zone (algal zone) below the surface.

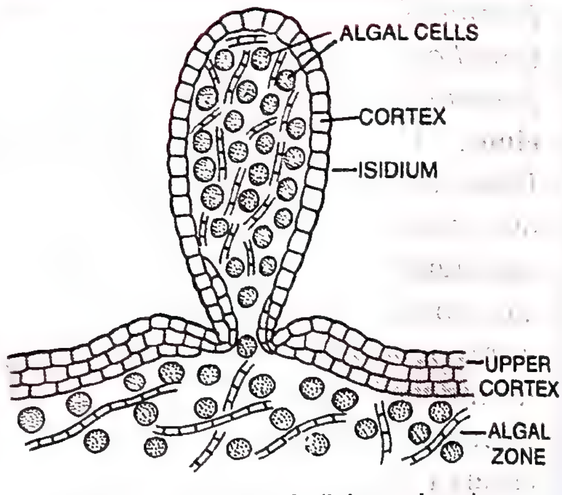


Fig. 2.55. Part of V.S. lichen showing an isidium and algal zone.

Relationships. The fungus performs three functions : (i) Body structure and covering (ii) Anchoring (iii) Absorption of water and minerals. It can absorb water from wet air (atmosphere), dew and rain. Minerals are picked up both from substratum and atmosphere. Special chemicals are excreted by the fungus partner of the lichen to dissolve minerals from the substratum.

The major function of alga is photosynthesis. The cyanobacterial alga additionally takes part in nitrogen fixation. The alga picks up water and mineral salts from the fungus while the fungus obtains part of the food manufactured by the alga. Therefore, in a lichen the association between alga and fungus is that of mutual benefit (mutualism) popularly called **symbiosis**. However, at times the fungus is found to (i) send haustoria into algal cells (ii) induce alga to secrete organic substances and (iii) prevent the alga to develop pectic covering. Therefore, some workers believe that the fungus is a **controlled parasite** over the alga (Ahmadjian, 1963). The phenomenon is called **helotism**.

Despite the knowledge about the algal and fungal components of a lichen and their mutual relationships, it has not been possible till now to create an artificial lichen.

Reproduction. Lichens multiply by four methods : (i) **Progressive death and decay** resulting in the separation of a lichen into two or more parts. (ii) **Fragmentation** caused by mechanical injury due to wind, trampling or animal bites. (iii) **Isidia** are superficial outgrowths of the lichens which are primarily meant for increasing surface area and photosynthetic activity. At times, they are broken off. Each isidium is capable of forming a new lichen because it has a core of algal cells surrounded by a sheath of fungal hyphae. (iv) **Soredia.** They are microscopic lichen propagules which are produced in large numbers inside sori called **pustules**. Soredia are dispersed by air currents. After falling on a suitable substratum each soredium gives rise to a lichen because it has a few algal cells surrounded incompletely by a weft of fungus.

Importance. (1) **Early Colonisers.** Lichens are early or pioneer colonisers of barren dry and naked rocks, cliffs, mountains and new terrains. During their growth lichens etch the rocks and cliffs by secreting acids. It produces minute crevices where organic matter accumulates. It paves the way for growth of mosses and grasses. (2) **Food.** In tundra, *Cladonia rangifera* (Reindeer Moss) constitutes the staple food of reindeer, caribou, musk ox, etc. *Certaria islandica* (Iceland Moss) is used as a food article in Iceland, Sweden and Norway. *Lecanora esculenta* is regarded as **bread of heaven** by Jews. In Bellary district, *Parmelia* (Rock Flower) is a table delicacy. *Endocarpon miniatum* (Stone Mushroom) is a vegetable in Japan. (3) **Dyes.** Orcein, a biological stain, is obtained from *Rocella tinctoria*.

The latter was also the source of litmus before the advent of synthetic product. Litmus is a pH indicator. (4) **Perfumes.** Scented incense is got from species of *Ramalina* and *Evernia*. Delicate perfume is got from *Lobularia pulmonaria* and *Evernia prunastri*. (5) **Medicines.** Usnic acid got from *Usnea* and *Cladonia* has antibiotic properties. It is used in preparation of ointment for burns and wounds. A number of drugs were obtained in older times from lichens. (6) **Air Pollution.** Decrease in lichen population of an area is indicative of air pollution particularly SO_2 pollution. (7) **Fires.** In hot season, *Usnea* may produce forest fires. (8) **Damaging Buildings.** In humid areas lichen can grow on window panes, marble and cement damaging the buildings by their etching activity.

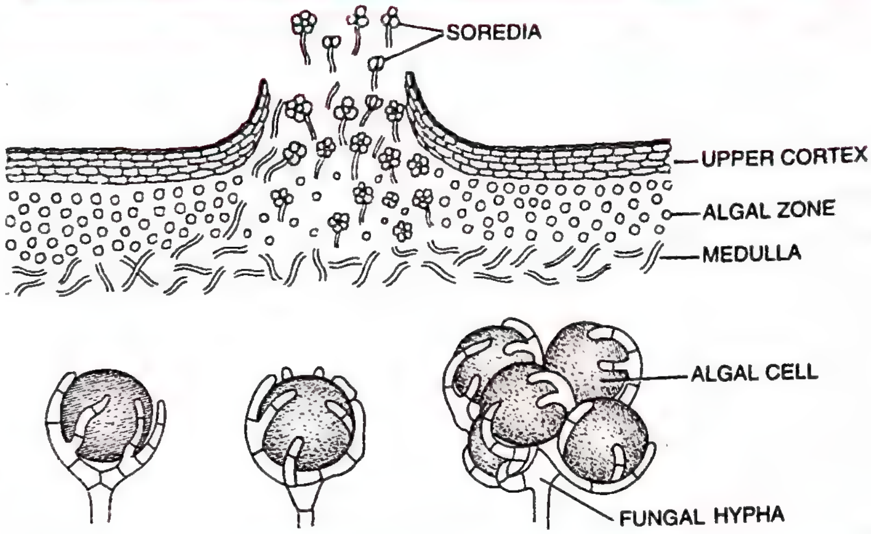


Fig. 2.56. A, part of V.S. lichen passing through a pustule of soredia. B, Soredia.

MYCORRHIZAE

The mutually beneficial or symbiotic association of a fungus with the root of a higher plant is known as mycorrhiza. Mycorrhizal roots often show a wooly covering of fungal hyphae. The shape is different from normal root— tuberous, nodulated, coralloid. Root cap and root hairs are absent. Mycorrhizal roots often remain in the upper layers of the soil where organic matter is abundant. Mycorrhizal association is not **very specific**. A plant can form association with several fungi. A birch tree is found to have mycorrhizal association with 13 species of fungi. The fungus is able to break the cell walls of the root cells to only a limited extent. As a result the fungus remains restricted to cortical region of the root. The vascular strand and growing point are not affected. Depending upon the residence of the fungus, mycorrhizae are of two types— **ectomycorrhizae** (= ectotrophic mycorrhizae) and **endomycorrhizae** (= endotrophic mycorrhizae). In ectomycorrhizae the bulk of the fungus lies on the surface of the root while a part of it lives in the intercellular spaces of the cortex. In endomycorrhizae only a little of the fungus lies on the root surface. It resides mostly inside the cortex of the root with some hyphal tips passing into the cortical cells.

In ectomycorrhiza (mostly trees) fungus forms association with a specific plant, *e.g.*, *Boletus*. In endomycorrhiza (nearly 80% of all, crop planets, herbs, shrubs, gymnosperms, ferns, liverworts) a fungus can form association with a number of plants, *e.g.*, *Glomus*. Networks of mycorrhizal fungi are always present in the soil.

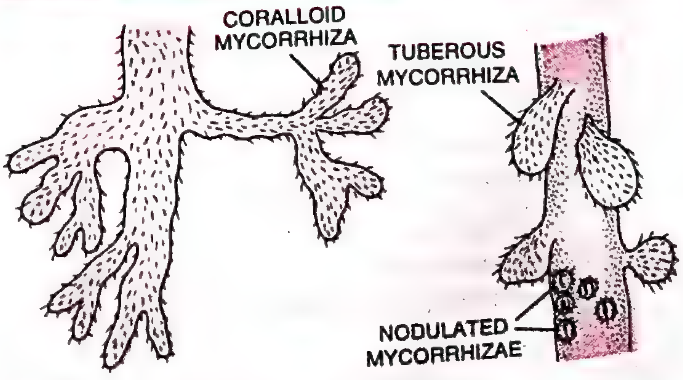


Fig. 2.57. Mycorrhizae of *Pinus*.

The fungus is dependent upon the higher plant for shelter and food. It obtains its nourishment from the cortical cells of the root.

The fungal hyphae are intercellular where the root cells excrete sugars and other soluble food ingredients. Intracellular hyphae develop where the root cells do not excrete food materials. Such hyphae obtain nourishment directly from inside the cells.

The fungus seems to be essential for proper growth of the plant having mycorrhiza. Many orchids do not survive without mycorrhiza. Several forest plants show stunted growth if they are deprived of root association with the fungus, *e.g.*, Birch, Pine. The plant is immensely benefitted from the association with the fungus. Fungal hyphae are spread in the soil over a large area. They take part in (a) Absorption of water. (b) Dissolving essential minerals present in the organic debris and handing over the same to the plant. This allows the plant to grow in areas deficient in inorganic minerals. (c) Absorbing inorganic salts present in the soil from over a large area. The forest trees like pines and birches are known to absorb 2–3 times more of potassium, nitrogen and phosphorus in the presence of mycorrhiza than in its absence. (d) The fungus produces various growth promoting substances. (e) It secretes antimicrobial substances which protect the young roots from attack of pathogens.

ADDITIONAL INFORMATION

- **Smallest Fungus**. Yeast.
- **Largest Fungus**. Mycelium of *Armillaria ostoyae* or Honey Fungus which can spread in an area of 600 hectares.
- **Aflatoxin**. *Aspergillus flavus*, growing on stored grains, groundnut and bread produces toxin called aflatoxin. It is carcinogenic.
- **Drosophila of Plant Kingdom**. *Neurospora crassa*.
- **Primary Host**. Host in which sexual stage of th parasite is passed. Also called definitive host and final host.
- **Secondary Host**. Host in which parasite passes its asexual phase. Also called intermediate host.
- **Reservoir Host**. An alternate or passive host or carrier that harbours the pathogen without being harmed and serves as a source of infection to others.
- **Collateral Host**. A substitute host in which the parasite can subsist with or without any apparent harm.
- **Autoecious**. Parasite passing its different stages in the same single host.
- **Digenetic**. Requirement of two alternate hosts for completion of life cycle of a parasite.
- **Heteroecious**. A parasite passing different stages of life history in different hosts.
- **Phytoalexins**. Chemicals produced by plant tissues in response to attack by a parasite for inhibiting the growth of the latter.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. What do the terms phycobiont and mycobiont signify ?

   ✓ Phycobiont is algal partner whereas mycobiont refers to fungal partner of lichen thallus. Phycobiont makes food while mycobiont provides protection and reproduction to lichen.

2. Give a comparative account of the classes of kingdom Fungi under the following :
   (i) mode of nutrition (ii) mode of reproduction.

   ✓ **Mode of Nutrition.**

Phycomycetes	**Ascomycetes**	**Basidiomycetes**	**Deuteromycetes**
Saprophyte or obligate Parasites	Saprophytes, parasites, decomposers or coprophilous	Saprophytes or parasites	Saprophytes or parasites or decomposers

Mode of Reproduction.

Phycomycetes	**Ascomycetes**	**Basidiomycetes**	**Deuteromycetes**
Asexual reproduction by zoospores or non-motile aplanospores; sexual reproduction by gametangial contact, gametangial copulation or planogametic copulation.	Asexual reproduction by conidia. Sexual reproduction by ascospores prcduced inside asci.	Asexual reproduction absent. Sexual reproduction by plasmogamy that produces basidiospores externally on basidia.	Reproduce asexually by conidia mainly. Sexual reproduction absent or not known.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Why are some fungi grouped under 'fungi imperfecti'?
   ✓ Sexual reproduction is absent in the artificial group of fungi called fungi imperfecti or deuteromycetes.
2. Define Mycology.
   ✓ Branch of biology dealing with the study of fungi is known as mycology.
3. Why the fungus is rarely noticed during its vegetative phase ?
   ✓ The fungus is seldom noticeable due to two reasons: (a) Hyaline nature of hyphae. (b) Occurrence of the major part of mycelium inside the substratum.
4. Name the food reserve form of fungi ?
   ✓ In the form of glycogen and oil.
5. What is pure culture ?
   ✓ Pure cultures of fungi are obtained from single spore of a strain having no contamination of other fungi.
6. Write the biological name for black bread mould ?
   ✓ *Rhizopus stolonifer* (= *R. nigricans*).
7. Which yeasts are called true yeasts ?
   ✓ Yeasts in which ascus formation is known are named as true yeasts.
8. Which fungal organism is often employed in the study of experimental genetics ?
   ✓ Neurospora (Pink Bread Mould), *e.g., N. crassa*.

Two Mark Questions (With Sample Answers)

1. Enlist the criteria considered to classify fungi ?
   ✓ A number of criteria are (a) Morphology and appearance of fungus (b) types of spores and their dispersal (c) Life cycle (d) Physiology (e) Biochemistry.
2. How are the delicate and soft fungal hyphae able to penetrate the hard timbers ?
   ✓ Fungus is able to break the cell walls of the root cells. As a result the fungus remains restricted to cortical region of the root.
3. What is conidium ? In which group/groups is it found ?
   ✓ **Conidia** are nonmotile exogenous spores which develop through abstriction at the tips or sides of special hyphae called conidiophores, *e.g., Pencillium, Aspergillus.*(members of Actinomycetes).

Three Mark Questions (Short Answer Type)

1. Differentiate between n, 2n and n + n conditions.
2. What is heterothallism ? Give its importance.
3. Why are lichens called pioneer colonisers? Name the lichen which is popularly called reindeer moss.
4. Write a brief account on mycorrhiza.

Five Mark Questions (Long Answer Type)

1. With neat diagrams describe the life history of a mushroom.
2. Briefly describe the life cycle of *Rhizopus*.
3. Discuss the structure and life cycle of yeast. Give its importance.
4. Discuss reproduction in fungi.

Miscellaneous Questions

1. To which groups of fungi do the following belong : ergot, puffballs, bread mould, yeast, morels and bracket fungi.
2. Give scientific term for (a) A cell with two haploid nuclei of different mating types.
   (b) The symbiotic association of a fungus with the root of higher plant.
   (c) Fruiting body of ascomycetes.

Multiple Choice Questions (With Answers)

(1) In *Agaricus*, the largest phase of nuclear condition is (a) n (b) 2 n (c) n + n (d) 3 n *(Kerala 2001)*

(2) Fungi imperfect is (a) Phycomycetes (b) Ascomycetes (c) Basidiomycetes (d) Deuteromycetes *(Kerala 2001)*

(3) Sporangiospores of Mucor are (a) Polyploid (b) Triploid (c) Diploid (d) Haploid. *(MP PMT 2002)*

(4) Edible part of mushroom is (a) basidiocarp (b) primary mycelium (c) basidiosphores (d) fungal hyphae *(CPMT 2003)*

(5) Litmus is got naturally from (a) Algae (b) Fungi (c) Lichens (d) Protozoans. *(Odisha 2004)*

(6) Clamp connections are found in (a) Ascomycetes (b) Zygomycetes (b) Saccharomycetes (d) Basidiomycetes. *(Odisha 2004)*

(7) Causal agent of red rot of sugarcane is (a) *Helminthosporium* (b) *Fusarium* (c) *Pythium* (d) *Colletotrichum* *(Odisha 2005)*

(8) In lichen, the fungus provides (a) Protection, anchorage and absorption for alga (b) Food for alga (c) Oxygen for alga (d) Fixes nitrogen for alga. *(CBSE 2005)*

(9) White rust of crucifers is (a) *Puccinia graminis* (b) *Ustilago tritici* (c) *Albugo candida* (d) *Aspergillus flavus* *(RPMT 2005)*

(10) In *Mucor* conjugation produces (a) Zoospore (b) Zygospore (c) Akinete (d) Arthrospore. *(RPMT 2006)*

(11) Red rot of sugarcane and white rust of mustard are respectively caused by (a) *Colletotrichum* and *Albugo candida* (b) *Colletotrichum* and *Fusarium* (c) *Pythium* and *Phytophthora* (d) *Albugo candida* and *Puccinia graminis.* *(Kerala 2006)*

(12) Ergot is got from (a) *Alternaria salani* (b) *Claviceps purpurea* (c) *Puccinia graminis* (d) *Fusarium oxysporium* *(CBSE 2007)*

(13) Soft rot disease of Sweet Potato is caused by (a) *Rhizopus stolonifer* (b) *Rhizopus sexualis* (c) *Chlamydomonas nivalis* (c) *Chlamydomonas coccifera.* *(JKET 2007)*

(14) Fungi differ from slime moulds in lacking (a) flagellated spores (b) zygospores (c) ascospores (d) basidiospores. *(DPMT 2008)*

(15) Fungi are classified on the basis of (a) asexual reproduction (b) sexual reproduction c) vegetative reproduction (d) none of these. *(DPMT 2008)*

(16) Cellulose occurs in the cell walls of (a) *Pseudomonas* (b) *Xanthomonas* (c) *Saccharomyces* (d) *Pythium.* *(CBSE 2008)*

(17) Which one has haplontic life cycle (a) *Funaria* (b) *Polytrichum* (c) Wheat (d) *Ustilago.* *(CBSE 2009)*

(18) Choose the wrong pair (a) Root not of vegetables — *Meloidogyne* species (b) Late blight of Potato — *Alternaria solani* (c) Black rust of wheat — *Puccinia graminis* (d) Loose smut of wheat — *Ustilago nuda.* *(CBSE 2009)*

(19) Bread Mould is (a) *Alternaria* (b) *Rhizopus* (c) *Penicillium* (d) *Aspergillus.* *(MP PMT 2010)*

(20) Black rust of wheat is caused by (a) *Ustilago nuda* (d) *Puccinia graminis* (c) *Alternaria solani* (d) *Xanthomonas oryzae.* *(CBSE 2010)*

(21) Powdery mildew of wheat is caused by (a) *Puccinia* (b) *Albugo* (c) *Erysiphe* (d) *Ustilago.* *(RPMT 2011)*

(22) Plant disease in which pathogen is seen as a cottony growth on the surface of host is (a) Rust (b) Smut (c) Powdery mildew (d) Downy mildew. *(CBSE 2011)*

(23) Lichens are composite organisms containing an alga and
(a) Fungus (b) Bacterium (c) Moss (d) Protozoan. *(HP PMT 2012)*

(24) *Puccinia graminis tritici* causes (a) yellow rust (b) white rust (c) black rust (d) brown rust. *(Chd. CET 2012)*

(25) Yeast is included in fungi and not protista because (a) It has eukaryotic organisation (b) Chlorophyll is absent (c) It forms pseudomycelium (d) Cell wall has cellulose and food reserve starch. *(JKCET 2013)*

(26) Pick up the wrong statement (a) Lichens are symbiotic associations (b) Lichens do not grow in unpolluted areas (c) Lichens are very good pollution indicators (d) Algal component of lichen is known as mycobiont (e) Fungal component of lichen is known as mycobiont. *(Kerala 2013)*

(27) The structure producing basidium is formed by the fusion of (a) two vegetative cells (b) two male gametes (c) two female gametes (d) male and female gametes. *(MH CET 2014)*

(28) A location with luxuriant growth of lichens on the trees indicates that the (a) trees are heavily infested (b) location is highly polluted (c) location is not polluted (d) trees are very healthy. *(CBSE 2014)*

(29) Morels and truffles are groups of fungi classified under
(a) Phycomycetes (b) Deuteromycetes (c) Basidiomycetes (d) Ascomycetes. *(AMU 2015)*

(30) Rust is a (a) Basidiomycete (b) Ascomycete (c) Phycomycete (d) Slime mould. *(Bihar 2015)*

(31) *Ustilago* is a member of kingdom (a) Monera (b) Fungi (c) Plantae (d) Animalia. *(AMU 2016)*

(32) Which of the following is **wrong** for fungi (a) they are both unicellular and multicellular (b) they are eucaryotic (c) all fungi possess a purely cellulosic cell wall (d) they are heterotrophic. *(NEET 2016)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as

(A) If both **A** and **R** are true and **R** is the correct explanation of **A**.
(B) If both **A** and **R** are true but **R** is not the correct explanation of **A**.
(C) If **A** is true but **R** is false.
(D) If both **A** and **R** are false.

1. **Assertion** : Fungi are widespread in distribution and they even live on or inside other plants and animals.
   Reason : Fungi are able to grow anywhere on land, water or on other organisms because they have a variety of pigments including chlorophyll, carotenoids, fucoxanthin and phycoerythrin. *(AIIMS 2005)*
   A B C D
2. **Assertion** : In fungi, sexual apparatus decreases in complexity from lower to higher forms.
   Reason : In algae, sexual apparatus increases in complexity from simple to higher forms.
   A B C D *(AIIMS 2007)*
3. **Assertion** : In basidiomycetes, basidiospores are produced endogenously in the basidium.
   Reason : In ascomycetes, ascospores are produced exogenously in ascus.
   A B C D *(AIIMS 2014)*
4. **Assertion** : Yeasts are unicellular fungi that are used in bakery and brewery industries.
   Reason : Potato spindle tuber disease is caused by viroids.
   A B C D *(AIIMS 2017)*
5. **Assertion** : *Neurospora* is commonly called water mould.
   Reason : It belongs to basidiomycetes.
   A B C D *(AIIMS 2017)*

ANSWERS

1. Ascomycetes, Ascomycetes, Zygomycetes, Ascomycetes, Ascomycetes, Basidiomycetes.
2. Dicaryotic cell, Mycorrhiza, Ascocarp.

Multiple Choice Questions

(1) —c (2) — d (3) — d (4) —a (5) —c (6) —d (7) —d (8) —a (9) —c (10) —b
(11) —a (12) —b (13) —a (14) —a (15) —b (16) —d (17) —d (18) —b (19) —b (20) —b
(21) —c (22) —d (23) —a (24) —c (25) —c (26) —b (27) —a (28) —c (29) —d (30) —a
(31) —b (32) —c

Assertion and Reason Type Questions

(1) —C (2) —B (3) —D (4) —B (5) —D

3 PLANT KINGDOM

- Plant Kingdom
  - Cryptogamae (Plants without seeds) Sex organs invisible
    - Thallophyta
      - Algae
    - Bryophyta
      - Hepaticopsida
      - Anthoceropsida
      - Bryopsida
    - Pteridophyta
      - Psilopsida
      - Lycopsida
      - Sphenopsida
      - Pteropsida
  - Phanerogamae (Plants with seeds) Sex organs visible
    - Gymnospermae
      - Cycadopsida
      - Coniferopsida
      - Gnetopsida
    - Angiospermae
      - Dicotyledons
      - Monocotyledons

DIVISION THALLOPHYTA

Thallophyta (Gk. *thallos*– undifferentiated, *phyton*– plant) comprises the simplest plants which possess undifferentiated or thallus like form, reproductive organs single celled nonjacketed called gametangia ; embryo stage, vascular and mechanical tissues are all absent. Differentiation of true roots, stems and leaves is also absent. Asexual reproduction by accessory spores is very common. Presently, it includes only Algae.

ALGAE

Algae (L. *Alga* – see weed) are chlorophyll-containing thallophytes and their relatives which are characterised by the absence of embryo stage and presence of nonjacketed gametangia where all the cells are fertile. In traditional two-kingdom classification all algae are grouped in plant kingdom alongwith bacteria and fungi. In Whittaker's classification, algae are grouped in three kingdoms— monera (blue-green algae), protista (dinoflagellates, diatoms, euglenoids) and plantae (red algae, brown algae and green algae).

Characters

1. Algae are usually aquatic, either marine or fresh water. Only a few algae occur in moist terrestrial habitats like tree trunks, wet rocks, moist soil, etc.

2. Plant body is thallus (a form without any differentiation into root, stem and leaves) which may be unicellular, colonial, filamentous, parenchymatous or pseudoparenchymatous.

3. Algae, like other aquatic plants, are covered over by mucilage. Mucilage protects the

algae from epiphytic growth and decaying effect of water. It also prevents desiccation if the algae happen to get exposed on the shores during low tide.

4. Vascular tissues are absent. Being aquatic, water conduction is not required. Some of the giant algae do have a system for conduction of food. The same is not needed in other algae because of their small size and presence of photosynthetic cells all over the body.

5. A mechanical tissue is absent. The body is flexible. It helps the algae to sway with water tides without being torn.

6. Nutrition is photosynthetic. Grana are absent in chloroplast. Algae contain chlorophyll *a*, carotenes and xanthophylls. Additional pigments like phycobilins, fucoxanthin occur in specific groups.

7. Vegetative and asexual modes of reproduction are abundant. Asexual spores are of two types, mitospores and meiospores. They are easily dispersed in aquatic habitat actively if motile and passively by water currents if nonmotile.

8. Sexual reproduction is absent in blue-green algae. In others, it is present. Sex organs are nonjacketed and one celled called gametangia. Sexual reproduction involves isogamy, anisogamy and oogamy in different groups.

9. An embryo stage is absent.

10. Life cycle is various— haplontic, diplontic or diplohaplontic.

Algae are usually differentiated on the basis of their pigments, flagellation and storage products (Table 3.1). Algae included under kingdom plantae by Whittaker (1969) are of three types— red algae, brown algae and green algae.

Differences Amongst Red, Brown and Green Algae

Red Algae	*Brown Algae*	*Green Algae*
1. Mostly marine	1. Mostly marine.	1. Mostly fresh water and subaerial.
2. Unicellular species fewer.	2. Unicellular species absent.	2. Unicellular species abundant.
3. Thylakoids are unstacked.	3. Thylakoids occur in groups of threes.	3. Thylakoids are stacked in groups of 2–20.
4. Chlorophyll— *a* and *d* type.	4. Chlorophyll– *a* and *c* type.	4. Chlorophyll— *a* and *b* type.
5. Fucoxanthin may be present.	5. Fucoxanthin is abundant.	5. Fucoxanthin is absent.
6. Phycobilins present.	6. Phycobilins absent.	6. Phycobilins absent.
7. Reserve food is floridean starch.	7. Reserve food is laminarin.	7. Reserve food is starch.
8. Motile stages are absent.	8. Present ; flagella 2, lateral and unequal.	8. Present ; flagella 2 to 8 apical and equal.
9. Cell wall contains cellulose and sulphated phycocolloids.	9. Cell wall contains cellulose and non-sulphated phycocolloids	9. Cell wall is of cellulose.

Economic Importance

1. **Food.** Some 70 species of marine algae are used as food, *e.g., Porphyra, Laminaria, Sargassum, Ulva.*

2. **Food Supplements.** *Chlorella* (green alga) and *Spirulina* (blue green alga) are rich in proteins. They can be used as food supplements even by space travellers.

3. **Photosynthesis.** Nearly 50% of total carbon dioxide fixation or photosynthesis of the world is carried out by algae. Photosynthesis releases oxygen in the immediate aquatic environment. It is essential for respiration of aquatic life.

4. **Primary Producers.** Algae are primary producers of food in large bodies of fresh, brackish and sea waters. This form the basis of food cycles of all aquatic animals.

5. **Phycocolloids** (Hydrocolloids). (i) **Agar** from *Gelidium* and *Gracilaria* is used as a culture medium, canning of fish and meat, sizing of textiles and paper. (ii) **Algin** from *Laminaria, Fucus* and *Sargassum* is used in stabilising emulsions (shaving creams, shampoos, ice creams, jellies) flameproof plastics, security glass and artificial fibres. (iii) **Carrageenin** from *Chondrus* is emulsifier and clearing agent.

6. **Sewage Disposal.** *Chlamydomonas, Chlorella, Scendesmus*, etc. are algae of sewage oxidation tanks which provide aerobic conditions for disposal of sewage by decomposer organisms.

Resemblances between Algae and Fungi

(i) Both occur in aquatic and semi-aquatic habitats. (ii) They have a simple body called thallus. (iii) A differentiation of stem, leaves and roots is absent. (iv) Asexual reproduction occurs by accessory or mitospores. (v) Sex organs are unicellular and nonjacketed. (vi) Gametic union does not produce an embryo stage.

Differences between Fungi and Algae

Fungi	*Algae*
1. Fungi live in aquatic, subaquatic and terrestrial habitats.	1. Algae do not occur in terrestrial habitats. They are aquatic or subaquatic.
2. Fungi lack chlorophyll and are heterotrophic in nutrition.	2. Algae usually possess chlorophyll and are autotrophic in nutrition.
3. They absorb organic nutrients from their environment.	3. They absorb inorganic nutrients from their environment.
4. Fungi usually live in darker places.	4. Algae live in well lighted areas.
5. The filaments or hyphae are usually branched.	5. The filaments, when present, may be branched or unbranched.
6. The hyphae may be compacted to form a false tissue called pseudoparenchyma. A parenchyma is seldom formed.	6. Parenchyma may be produced by division of cells in more than one plane.
7. The cell wall is commonly made of chitin or fungus cellulose.	7. Cell wall is made of true cellulose.
8. Food reserve consists of glycogen and oil globules. Starch is never formed.	8. Food reserve is starch (or related polysaccharide) and oil globules.
9. Motile spores (zoospores) and motile gametes are rare.	9. Motile spores and motile gametes are quite common.
10. In higher forms, karyogamy is delayed after completion of plasmogamy.	10. Plasmogamy is immediately followed by karyogamy.
11. There is progressive reduction of sexuality in fungi.	11. There is progressive evolution of sex amongst algae.

Red Algae— Rhodophyta (Gk, *rhodo*– red, *phyton*– plant)

Red algae are defined as eukaryotic algae which possess chlorophyll *a*, phycobilins, floridean starch as food reserve, abundant phycocolloids (like agar, carrageenin, funori) but lack flagellate cells.

1. Red algae/rhodophytes are an ancient group of algae with 5000 living species.
2. They are marine except for a few fresh water species (*e.g.*, *Batrachospermum*).

3. Red algae are autotrophic with the exception of a few like *Harveyella* which are colourless and parasitic on other red algae.

4. A motile or flagellate stage in the life cycle is absent.

5. The plant body varies from **unicellular** (*e.g., Porphyridium*), **filamentous** (*e.g., Spermothamnion*), **pseudoparenchymatous** (*Asterocystis*), **parenchymatous sheets** (*e.g., Porphyra*), **ribbons** (*e.g., Chondrus*) to graceful **lace-like** complex multicellular sea weeds (*e.g., Gelidium*).

6. Cell wall possesses cellulose, pectic compounds and certain mucopolysaccharides called **phycocolloids** (*e.g.,* **agar, carrageenin** and **funori**). The latter are usually sulphated.

7. Some red algae have an incrustation of calcium carbonate over their walls. They appear coral-like and are called **coralline** (*e.g., Corallina*). Coralline algae produce limestone. They are important component of **reef formations** alongwith corals.

8. The photosynthetic organelles called **chromatophores,** have unstacked or single thylakoids.

9. Photosynthetic pigments include chlorophyll *a*, carotenoids and **phycobilins**. Chlorophyll *d* has been reported in some cases. Phycobilins are water soluble pigments of two types, red coloured **phycoerythrin** and blue-coloured **phycocyanin** as well as **allophycocyanin.** Similar pigments also occur in cyanobacteria (blue-green algae).

10. The red colour of red algae is due to abundant formation of phycoerythrin. Phycoerythrin is able to absorb blue green wavelengths of light. Being shorter, these wavelengths are able to reach the maximum depth in water. Therefore, red algae reach the maximum depth in sea where no other type of photosynthetic organisms grow. However, rhodophytes living in shallower waters do not appear reddish due to lesser synthesis of phycoerythrin.

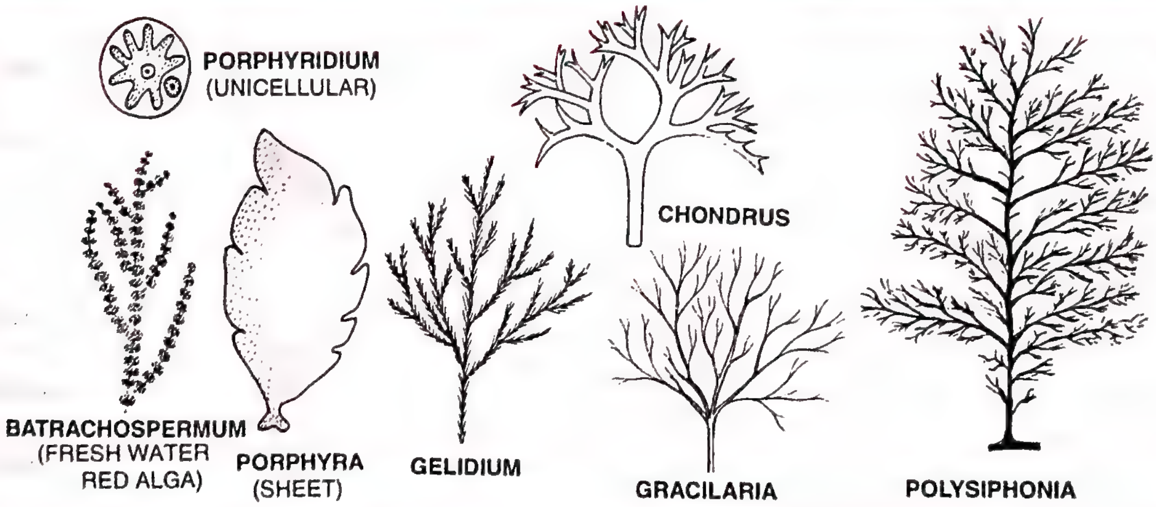


Fig. 3.1. Some Red Algae.

11. Reserve food is **floridean starch**. In constitution, it is very much similar to glycogen or amylopectin.

12. Asexual reproduction takes place through a variety of **spores**— neutral spores, monospores, tetraspores, carpospores, gemmae.

13. Sexual reproduction is **oogamous**. The male sex organ is called spermatangium or antheridium. It produces nonflagellate male gamete known as **spermatium**. The female sex organ is flask-shaped and is termed **carpogonium**. Carpogonium possesses an elongated receptive organ named **trichogyne**. Spermatia are carried by water currents to trichogyne

tips for effecting fertilization. The female sex organ remains attached to the plant and forms a new structure called **carposporophyte**.

14. Multicellular forms have an alternation of haploid and diploid generations.

Common Red Algae

Gelidium (Fig. 3.1). It is a stiff cartilaginous pinnately branched agar yielding red alga that is attached to the substratum by a number of rhizoids. Appearance is lace-like. Gelidium is the major source of agar which is obtained from cell wall. Agar has been under manufacture in Japan since 1760.

Porphyra (Fig. 3.1). It is an edible (Laver, Nori, Amanari) flat thalloid marine red alga. The thallus is made of 1–2 layers of cells covered on the outside by a cuticle of solidified gel. Asexual reproduction occurs by means of **neutral spores**. Sexual reproduction produces a diploid zygote which on. Meiosis forms haploid **carpospores**. Each carpospore grows into a filamentous structure called **conchocelis stage**. The stage may multiply by means of **monospores**. Ultimately conchocelis stage produces the typical flat parenchymatous thallus.

Batrachospermum (Fig. 3.1). It is a fresh water filamentous rhodophycean alga, commonly called **frog spawn alga**. The colour depends upon depth at which the alga occurs—blue-green to purple, violet and pink. The filament gives a branched beaded appearance. The beads occur in the region of nodes where whorls of short branches or glomerules occur. The alga multiplies asexually by monospores. Male sex organs are called **spermatangia** while female sex organs are called **carpogonia**. Meiosis occurs immediately after fertilization. A haploid **carposporophyte** or **cystocarp** is formed. It produces **carpospores**. A carpospore forms a highly branched filamentous **chantransia stage**. It is juvenile stage which can multiply by monospores. The adult alga grows over the chantransia stage.

Gracilaria (Fig. 3.1). It is an agar yeidling red alga (**agarophyte**) which grows in lagoons. The thallus is branched, cartilaginous, cylindrical or compressed cylindrical. Plants are unisexual.

Polysiphonia (Fig. 3.1). It is a small upright bushy marine alga with feathery multiaxial structure. The plants are fixed to the substratum by rhizoids, holdfast or prostrate system. The plant bears two types of branches, dwarf and long. Dwarf branches are **trichoblasts**. They develop sex organs, antheridia on male plants and carpogonia on female plants. Cells show pit connections. Fertilization produces diploid **cystocarp** or **carposporophyte**. The latter bears diploid carpospores. On germination each carpospore forms a **tetrasporophyte** which resembles the gametophytic plant body in morphology. Tetrasporophyte develops haploid tetraspores. A tetraspore germinates to produce gametophytic plant body. Life cycle is diplo-diplohaplontic and triphase with one gametophytic (n) and two sporophytic (2n) phases.

Polysiphonia has been one of the sources of bromine.

Polysiphonia (n) — Spermatangium → Spermatium — Zygote 2n → Cystocarp 2n → Carpospore 2n → Tetrasporophyte 2n
└ Carpogonium ——————┘
Tetrasporophyte 2n ↓ meiosis → Tetraspore (n) → Polysiphonia (n)

Economic Importance

1. **Food**. A number of red algae are edible, *e.g.*, *Porphyra* (Laver), *Rhodymenia* (Dulse).

Chondrus (Irish Moss). *Rhodymenia* (also called sheep's weed) is also used as fodder. *Porphyra* is cultivated in Japan for commercial exploitation.

2. **Phycocolloids.** A number of phycocolloids are extracted for commercial use. They include agar, carrageenin and funori. **Agar** is used in solidifying laboratory culture media and is added as stabiliser or thickener in the preparation of jellies, puddings, creams, cheese, bakery, etc. Agar is obtained from cell wall of *Gelidium* and *Gracilaria*. **Carrageenin** is used as a clearing agent in liquors, leather finishing and as emulsifier in chocolates, ice-creams, tooth pastes, paints, etc. It is extracted from *Chondrus*. **Funori** is a glue used as adhesive and in sizing textiles, papers, etc. It is got from *Gloiopeltis*.

3. **Bromine.** Bromine is obtained from some of the red algae, *e.g., Rhodomela Polysiphonia*.

4. **Medicines.** *Corallina* is capable of curing worm infections. *Polysiphonia* has anti-bacterial properties. Agar is laxative. Carrageenin can coagulate blood.

Brown Algae— Phaeophyta (Gk. *phaios*– brown, *phyton*– plant)

Brown algae are eucaryotic marine algae which possess chlorophyll *a*, chlorophyll *c*, abundant fucoxanthin, phycocolloid algin and reserve food in the form of laminarin.

1. Brown algae comprise about 2000 species.
2. Majority of the brown algae are **marine**.
3. Brown algae generally occur in both tidal and subtidal regions of colder seas.
4. Unicellular forms are **absent**.

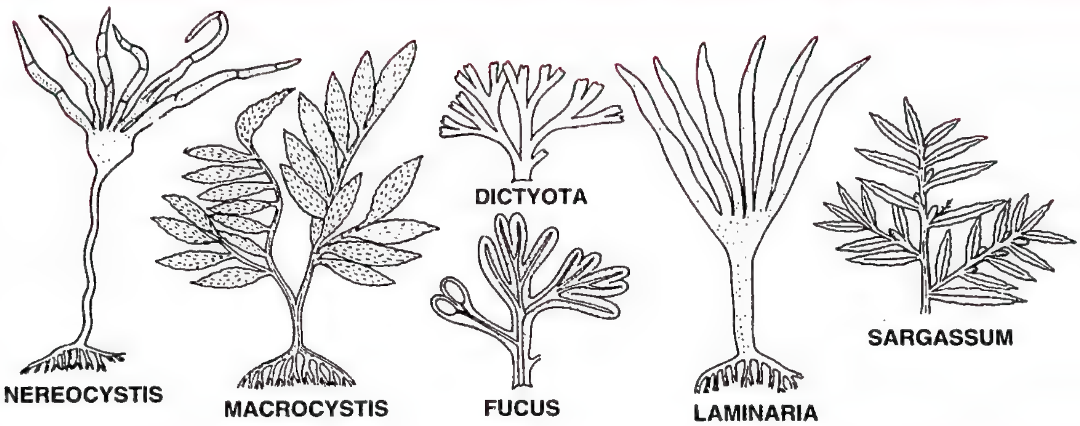


Fig. 3.2. Some Brown Algae.

5. The body consists of a branched filamentous structure in lower forms (*e.g., Ectocarpus*) and parenchymatous structure in higher forms (*e.g.,Sargassum, Laminaria, Fucus, Macrocystis*).

6. Brown algae include the largest algae. The giant brown algae are called **kelps**. The largest kelps are *Macrocystis* (40–100m) and *Nereocystis* (20–30m).

7. The plant body is often differentiated into holdfast, stipe and lamina (frond).

9. Lamina may be simple or divided variously. Despite its size and complexity of form, lamina of a kelp is annual. Lamina (frond) is photosynthetic.

10. The large forms often possess **air vesicles** or bladders for providing buoyancy.

11. Cell wall contains cellulose, nonglucan saccharides and phycocolloids.

12. **Phycocolloids** of brown algae are nonsulphated mucosaccharides. The common ones are **alginic acid, fucoidin** and **fucin**. They are copious in species dwelling tidal areas.

Phycocolloids protect the algae from desiccation during low-tide, freezing under low temperature and injury when beaten against rocks.

13. Photosynthetic organelles or chromatophores possess 3-thylakoid lamellae.

14. Photosynthetic pigments include chlorophyll *a*, chlorophyll *c* and carotenoids (carotenes and xanthophylls). The brown colour of algae is due to the presence of large amount of xanthophyll called **fucoxanthin**.

15. Food reserve is **laminarin** (carbohydrate) and lipid.

16. Cells possess refractile vesicles called **fucosan vesicles**. The vesicles contain a phenolic chemical named fucosan. Fucosan is colourless inside water but becomes brown or black on exposure to air.

17. Conducting tubes or **trumpet hyphae** are present in larger brown algae or kelps. The tubes possess sieve septa. They take part in conduction of food materials. The rate is 38–78cm/hr.

18. Asexual reproduction occurs with the help of both motile and nonmotile spores (*e.g.*, neutral spores, tetraspores, monospores). The motile spores or zoospores are biflagellated and have **heterokont** flagellation with one smaller whip like smooth flagellum and other larger of tinsel type.

19. Sexual reproduction varies from isogamy, anisogamy to oogamy. In isogamy and anisogamy both the gametes are motile with heterokont flagellation. In oogamy, only the male gametes are motile or flagellate. The female gametes are nonmotile.

20. Isomorphic alternation of generations is found in some brown algae, *e.g.*, *Ectocarpus*, *Dictyota*. Here both the haploid and diploid generations are present and are similar in structure. In many brown algae, the diploid generation or phase is dominant. The haploid generation or phase is either microscopic or represented by gametes only (*e.g.*, *Fucus*).

Common Brown Algae

Laminaria (Fig. 3.2). It is a wide spread kelp or large-sized brown alga popularly called **devil's apron**. The size is 1–3 metres. Plant body is sporophyte. It is differentiated into basal holdfast, a near cylindrical stipe and a flattened blade or lamina. Alternation of generations is heteromorphic.

Laminaria is a source of food, manure, algin and iodine.

Dictyota (Fig. 3.2). It is a ribbon shaped dichotomously branched marine brown alga that grows in shallow waters. Frond is flat, dichotomously branched. The surface of the frond bears hair and unilocular sporangia. Unilocular sporangia produce haploid tetraspores. Each tetraspore produces haploid gametophytic thallus that is similar in morphology to sporophytic thallus. Sex organs are borne in clusters or sori. Male sex organs or antheridia produce uniflagellate sperms. Fertilization produces diploid zygote which germinates to produce diploid plant body.

Fucus (Fig. 3.2). It is a leathery flat branched perennial brown alga of small size which has been a source of fodder, manure and algin. Frond is flat and branched both dichotomously and monopodially. A pair of **pneumocysts** or **air bladders** occur in the region of branching. At places the branches contain flask-shaped cavities called **conceptacles**. Meiosis occurs during gamete formation.

Sargassum (Fig. 3.2). *Sargassum* is popularly called **gulf weed** which is used both as fodder and manure. **Sarganine** is an antibacterial and antifungal extract obtained from it. Both free floating and attached forms occur. Floating forms are common in part of North

Atlantic ocean called Sargasso sea where these are menace to shipping. In attached forms, the plant has three parts— holdfast, main axis and laterals. Main axis bears long laterals on which are borne short laterals or leaves. Pneumocysts or air bladders occur at places in the axils of leaves. In free floating forms, pneumocysts provide buoyancy for floating while in attached forms they provide buoyancy for keeping the plants upright. Sex organs are borne in two different types of **conceptacles**.

Ectocarpus (Fig. 3.3). It is a filamentous marine brown alga which has both upright and prostrate regions. Such a growth is called **heterotrichous**. Upright branches show **evection** (pushing of parent branch) to give an appearance of dichotomy. Fixation to solid substratum occurs through prostate portion and rhizoids. Reproduction occurs by fragmentation. The plants can also multiply asexually through the formation of diploid biflagellate zoospores in plurilocular (= neutral) sporangia. The sporophytic plant body also bears unilocular sporangia in which sporic meiosis occurs and haploid biflagellate meiozoospores are formed. The latter germinate to produce gametophytic thalli. The gametophytes liberate biflagellate gametes from their plurilocular gametangia. The gametes fuse to form diploid zygote that germinates to produce diploid plant.

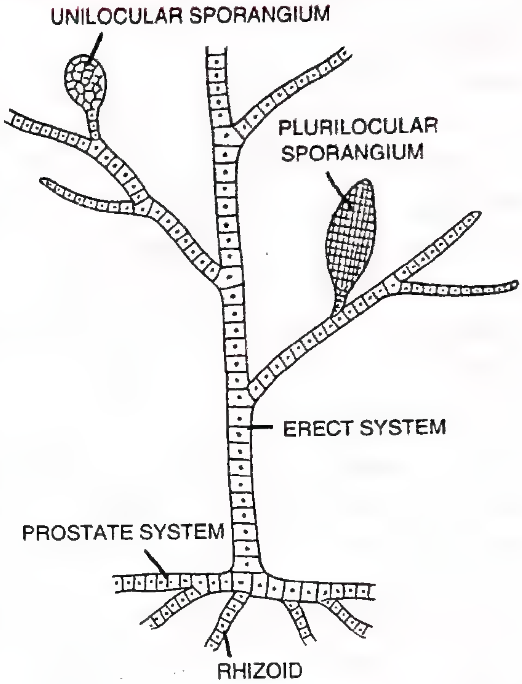


Fig. 3.3. *Ectocarpus*.

Economic Importance

1. **Food**. A number of brown algae are used as food in some countries, *e.g., Laminaria, Alaria, Macrocystis, Sargassum*. The edible brown algae are also used as fodder.

2. **Fouling of Ships**. Some brown algae get attached to hulls of ships, *e.g., Ectocarpus*. Others floating in masses (*e.g., Sargassum*) have a nuisance value for ships.

3. **Iodine**. *Fucus* and *Laminaria* are rich source of iodine. Potash is abundant in *Macrocystis* and *Nereocystis*.

4. **Medicines**. Sodium laminarin sulphate is blood anticoagulant. *Laminaria* and *Ascophyllum* have antibiotic properties, while *Durvillea* has worm expelling or vermifuge properties.

5. **Alginic Acid**. It is phycocolloid which is obtained commercially from *Laminaria, Macrocystis, Nereocystis, Fucus, Sargassum* etc. Alginic acid and its salts are used in obtaining emulsions (ice- creams, ointments, toothpastes, cosmetics, creams, shampoos, etc.), sizing textiles, flame proof plastics, security glass, formation of pills and surgical threads.

Green Algae— Chlorophyta (Gk. *chloros*– green, *phyton*– plant)

Green algae are defined as a group of eukaryotic algae which resemble land plants in having cellulosic cell wall, starch as food reserve and both chlorophyll *a* as well as chlorophyll *b* as photosynthetic pigments.

1. The group contains about 7000 living species (20,000 according to Prescott, 1969).

2. Green algae occur in all types of habitats. Only ten percent of green algae are marine. Majority of the species are fresh water. Several members are subaerial. They grow on moist

soils, walls, rocks and tree trunks. Strains of *Chlorella* can bear moderate hot waters. Some forms live in snow or frozen lakes (*e.g., Scotiella, Hormidium*).

3. Some species are epiphytic, endophytic, epizoic or endozoic. *Zoochlorella* is associated with sponges. *Characium* occurs on crustaceans, *Cladophora* on molluscan shells, while *Trichophilus* provides green colour to the fur of tree-dwelling sloth (a mammal) found in the rain forests of South America. The alga gives protective colouration to the sloth. Certain green algae are constituents of lichens. *Cephaleuros* is **parasitic** on a number of higher plants. It reduces the yield of tea, coffee, pepper and citrus fruits.

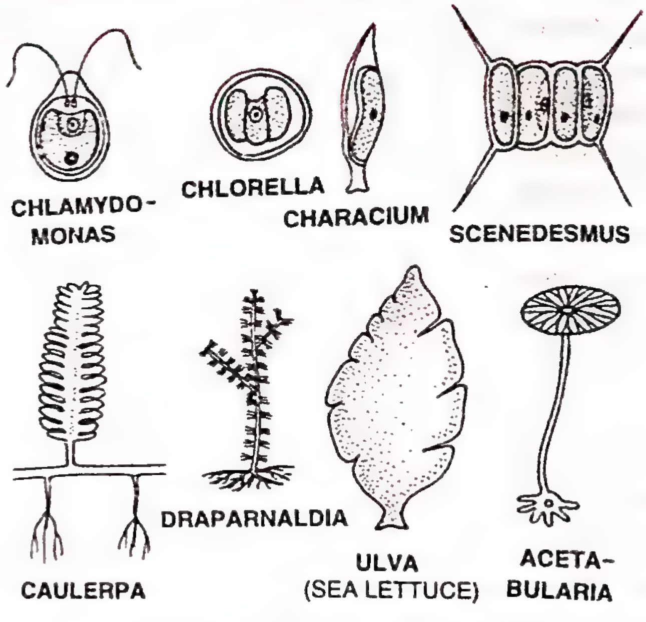


Fig. 3.4. Some Green Algae.

4. Thallus is various— unicellular flagellate (*e.g., Chlamydomonas*), unicellular nonflagellate (*e.g., Chlorella, Characium, Acetabularia* or umbrella plant which is several centimeters in length and is differentiated into uninucleate holdfast, an elongated stalk and umbrella-like cap.), flagellate colonies (*e.g., Volvox*), nonflagellate colonies (*e.g., Scenedesmus, Hydrodictyon*), coenocytic and siphonaceous (*e.g., Caulerpa*), heterotrichous (with prostrate and vertical branches, *e.g., Draparnaldia*), and parenchymatous (*e.g., Ulva*).

5. Cell wall contains cellulose with a few exceptions in the inner layer and pectose in the outer layer.

6. Chloroplasts have 2–20 thylakoid lamellae.

7. Photosynthetic pigments are similar to those of higher plants— chlorophyll *a*, chlorophyll *b*, carotenes and xanthophylls. The colour is grass-green due to predominance of chlorophylls.

8. Food reserve is starch but some forms possess oil drops.

9. Chloroplasts generally contain 1 to many **storage bodies** called pyrenoids. Pyrenoids contains protein and starch.

10. In flagellate forms, an eye spot is present in the chloroplasts.

11. Asexual reproduction takes place by both mitospores and meiospores. The common asexual spores are zoospores, aplanospores, hypnospores, akinetes, autospores, etc.

12. Sexual reproduction is effected by isogamy, anisogamy and oogamy. In **isogamy** both the fusing gametes are morphologically and physiologically similar. They may be flagellate or nonflagellate. In **anisogamy** the fusing gametes are structurally similar but differ in size and behaviour. One of the two gametes is larger and is called macrogamete or female gamete. The other is smaller and is termed microgamete or male gamete. In **oogamy** there is a large food laden nonflagellate female gamete called egg or oosphere. The male gamete or antherozoid is smaller and motile.

Differences between Isogamy and Anisogamy

Isogamy	*Anisogamy*
1. The fusing gametes are similar in structure, size and behaviour.	1. The fusing gametes differ in size and behaviour.
2. There is no distinction of male and female gametes.	2. A distinction of male and female gametes is present.
3. There is equal storage of food in the fusing gametes.	3. More food is stored in female gametes.

Common Green Algae

Chlamydomonas (Fig. 3.5). It is a microscopic (10–30 μm), eukaryotic, unicellular, pyriform, biflagellate green alga of both fresh water and marine habitats, generally rich in ammonia salts. Cell wall consists of glycoprotein. Cellulose is absent. There is an apical papilla. Internally, the alga possesses a single nucleus, two contractile vacuoles for osmoregulation and excretion, a cup-shaped chloroplast with a red eye spot or stigma and a pyrenoid for storing starch.

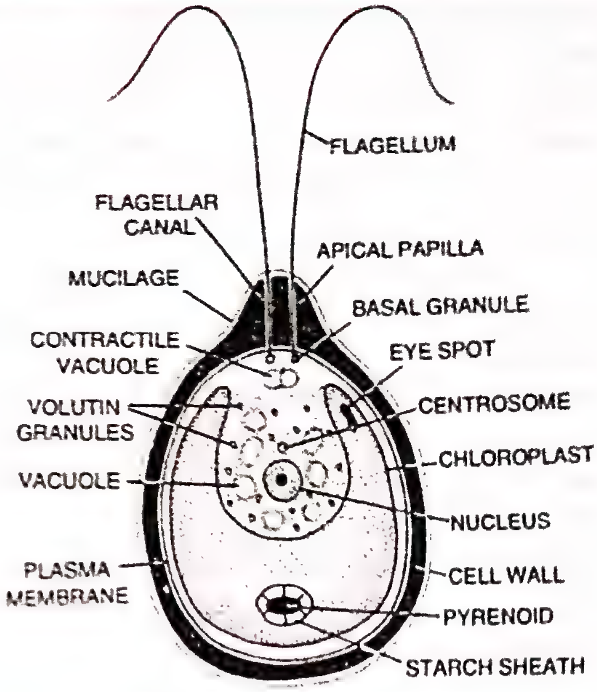


Fig. 3.5. A, *Chalmydomonas.*

Asexual reproduction occurs through formation of zoospores, aplanospores, hypnospores and **palmella stage**. In palmella stage, a large number of near naked cells devoid of flagella lie inside a mass of mucilage. The stage develops in response to toxic chemicals and unfavourable water conditions. Zoospores are flagellate spores while aplanospores and hypnospores are non-motile. Aplanospores are thin-walled. Hypnospores are thick-walled. They often possess reddish pigment haematochrome. Red snow caused by *C. nivalis* is due to red coloured hypnospores.

Sexual reproduction can occur by isogamy, hologamy (fusion of young cells), anisogamy and oogamy. It shows zygotic meiosis and thus life cycle is haplontic.

Volvox (Fig. 3.6). It is a fresh water green hollow ball like colonial alga of 0.5–2 mm diameter. Colony of *Volvox* is hollow and has a fixed number of cells (500 to 60,000). It is called **coenobium**. The cells are interconnected by cytoplasmic strands. They are biflagellate. Some cells of the posterior region are large. They function as reproductive cells or gonidia. The whole colony or coenobium swims by joint activity of its flagellate cells. The alga rotates during swimming. It is, therefore, also called **rolling alga**. Asexual reproduction occurs by formation of daughter colonies. Sexual reproduction is oogamous.

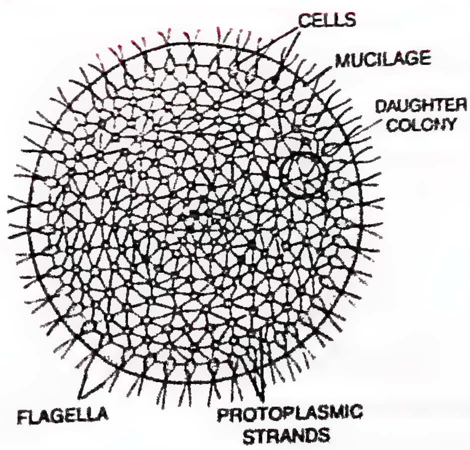


Fig. 3.6. *Volvox.*

Ulothrix (Fig. 3.7). It is an attached, unbranched, green, filamentous alga of fresh aerated waters. Filaments are covered by mucilage. They are attached to a solid substratum by means

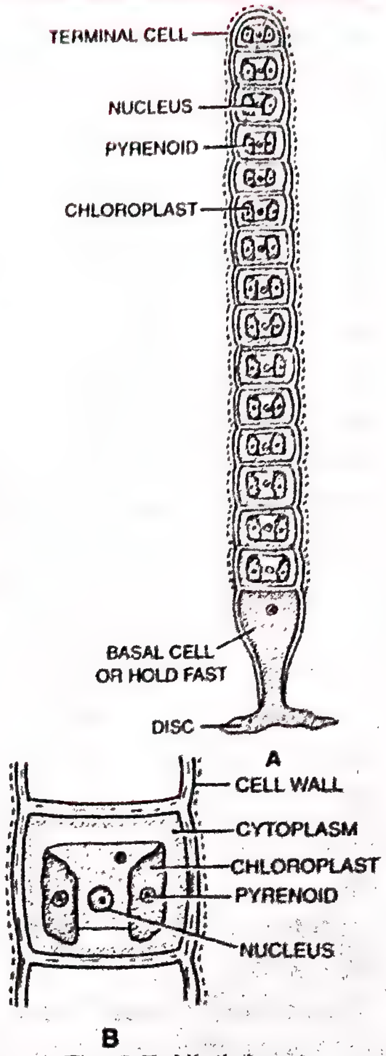


Fig. 3.7. Ulothrix. A, Filament. B, A cell.

of a colourless lowermost cell called **holdfast**. The remaining cells are green. They are cylindrical and quadrate. The cells are uninucleate. They have central vacuoles. The peripheral protoplast possesses a single girdle-like or collar shaped chloroplast studded with a few pyrenoids. Every green cell is capable of growth, photosynthesis and reproduction. Vegetative reproduction occurs through fragmentation. Asexual reproduction takes place through zoospores, aplanospores, hypnospores and akinetes.

Sexual reproduction is isogamous. Life cycle haplontic.

Spirogyra (Fig. 3.8). It is an unbranched, mucilage covered green filamentous alga that forms free floating masses over the surface of fresh water ponds. It is called **pond scum, water silk** or **mermaid tresses**. All the cells are green, elongated, cylindrical, capable of growth, division and taking part in reproduction. A non-green holdfast occurs in attached species. A green cell contains 1–16 spirally coiled ribbon shaped chloroplasts studded with medianly arranged pyrenoids. There is a single nucleus suspended in the central vacuole by means of cytoplasmic strands.

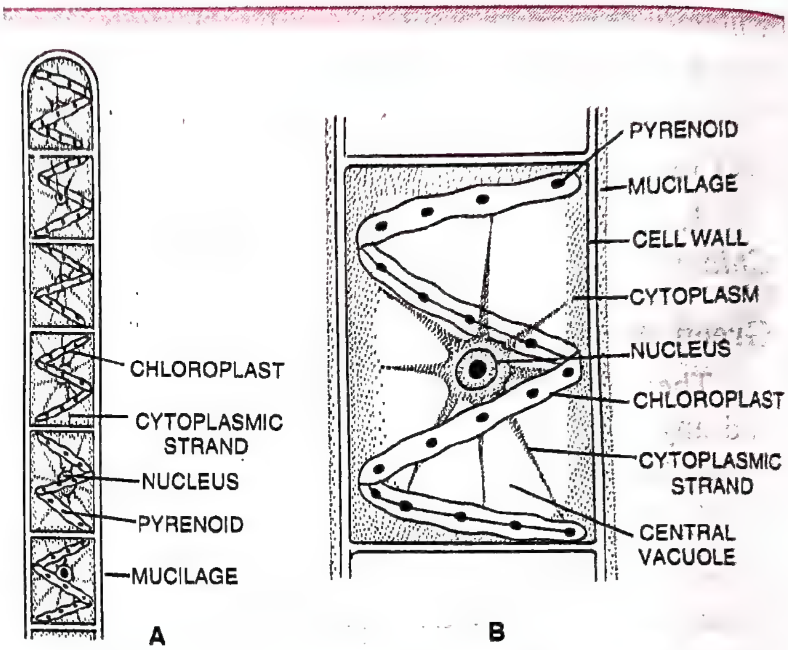


Fig. 3.8. *Spirogyra*. A, Part of filament. B, Cell.

Spirogyra multiplies vegetatively by fragmentation. Asexual reproduction by spores is rare. Sexual reproduction occurs by **conjugation**. Gametes are isogamous and nonflagellate (aplanogametes). Conjugation occurs by two methods, scalariform conjugation and lateral conjugation. In **scalariform conjugation** opposite cells of two filaments develop conjugation tubes. Gamete of one cell called male gamete is more active, passes through conjugation tube and fuses with gamete or female gamete of the cell of the second filament. In **lateral conjugation**, two adjacent cells of the same filament function as male and female cells. Male gamete passes into female cell either through a conjugation tube (indirect lateral conjugation, *e.g., S affinis*) or through a central pore (direct lateral, *e.g., S. jogensis*). Zygote develops into a resting thick walled zygospore. On approach of favourable season next year, zygospore undergoes meiosis but produces only a single filament due to degeneation of three of the four haploid nuclei. Development of zygote is direct. Life cycle is haplontic.

Chara (Fig. 3.9). *Chara* or **aquatic horse-tail** is a green alga found growing at the bottom of shallow fresh waters like ponds, pools and lakes. Lime incrustation may occur in some species (hence **stonewort**). *Chara* is food for many aquatic animals. It can be used as a manure. Mosquito larvae do not occur in *Chara* waters. The plant is fixed to the substratum by means of highly branched multicellular rhizoids. The axis of the plant is jointed. The joints represent

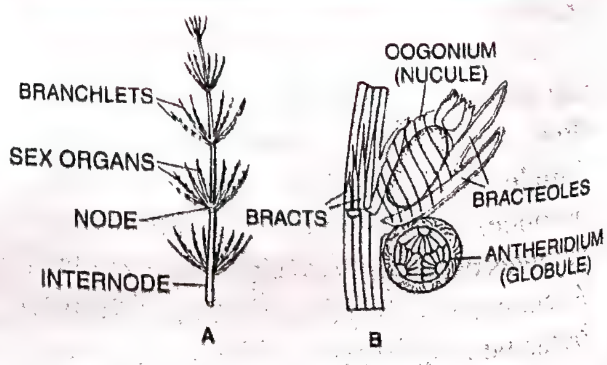


Fig. 3.11. *Chara*. A, Thallus; B, Sex organs.

nodes having whorls of short laterals with an occasional long lateral. Male sex organ is rounded called **antheridium** (= globule). It lies below the ovate shaped female sex organ called **oogonium** (= nucule). Both antheridium and oogonium have multicellular coverings which bring them close to sex organs of bryophytes. *Chara* can multiply vegetatively through fragmentation, tubers, bulbils, amylum stars and secondary protonemata.

Economic Importance

1. **Food.** A number of green algae are used as food, *e.g., Ulva, Caulerpa, Enteromorpha. Chlorella* can yield food rich in lipids, proteins, vitamins and minerals.

2. **Antibiotics.** They can be extracted from *Chlorella* and *Caulerpa.*

3. **Parasites.** *Cephaleuros virescens* causes **red rust of tea** and reduces yield of tea. It also reduces the yield of coffee, pepper, citrus, etc.

4. **Sewage Oxidation.** Sewage oxidation ponds contain a number of green algae, *e.g., Chlamydomonas, Chlorella, Scenedesmus.*

Green Algae as Ancestors of Land Plants

There are no biochemical, cytological and morphological similarities between land plants and any other group of algae except the green ones or chlorophyta. The various evidences which favour the chlorophycean origin of land plants are :

(i) Both green algae and land plants possess the same type of chlorophylls, *a* and *b.*
(ii) The carotenoid pigments are similar in the two groups.
(iii) Cell wall contains similar cellulose and pectic compounds in the two groups.
(iv) Starch is the common storage carbohydrate in the two groups.
(v) The flagella are similar in the motile forms of the two.

BRYOPHYTES— Bryophyta (Gk. *bryon*– moss, *phyton*– plant)

Bryophytes are nonvascular terrestrial plants of moist habitats in which a multicellular diploid sporophyte lives as a parasite on an independent multicellular haploid gametophyte that develops multicellular jacketed sex organs.

1. The plants are small. They seldom attain great length or height, the maximum being 60 cm for a moss species growing in New Zealand.

2. Roots absent. Instead rhizoids occur. The latter may be unicellular or multicellular.

3. Accessory spores are not formed. Vegetative reproduction is quite common through fragmentation, tubers, gemmae, buds, adventitious branches, etc.

4. Sex organs are multicellular and jacketed. They are of two types (Fig. 3.10), male **antheridium** and female **archegonium**. Antheridium produces a number of flagellate male gametes called sperms or antherozoids. Archegonium is flask-shaped with tubular neck and a swollen venter. The single- layered wall of neck has 5–6 rows of cells. Internally it encloses a

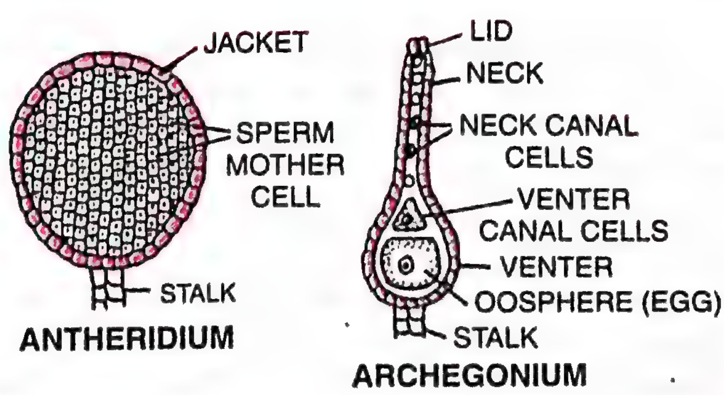


Fig. 3.10. Antheridium and archegonium.

few sterile neck canal cells. The wall of venter is 1–2 layered. It encloses a venter cavity having a sterile venter canal cell and a fertile egg or oosphere.

5. An external layer of water is essential for the swimming of male gametes to the archegonia.

Differences between Antheridia and Archegonia

Antheridia	*Archegonia*
1. They are male organs of bryophytes and pteridophytes.	1. They are female organs of bryophytes, pteridophytes and gymnosperms.
2. Antheridia are generally rounded in outline.	2. Archegonia are usually flask-shaped in outline.
3. Sterile cells are absent inside.	3. Sterile cells occur in the interior of archegonia.
4. An antheridium forms a large number of male gametes.	4. An archegonium encloses a single female gamete.
5. The male gametes produced in an antheridium are usually motile.	5. The female gamete or egg present in an archegonium is usually non-motile.

6. The sporophyte in bryophytes is also called **sporogonium** as it is attached and dependent on gametophyte. It produces haploid meiospores inside its capsule part.

7. On germination each spore produces a gametophyte either directly or through a juvenile filamentous stage called protonema.

8. Bryophytes show heteromorphic or heterologous alternation of generations.

Differences between Gametophyte and Sporophyte

Gametophyte	*Sporophyte*
1. It is haploid phase of life cycle.	1. It is diploid phase of life cycle.
2. It is specialized to produce gametes.	2. It produces spores called meiospores.
3. All divisions are mitotic.	3. Meiosis occurs during formation of meiospores.
4. It is sexual generation.	4. It is asexual generation.
5. Fusion of gametes produces zygote.	5. Meiospores form gametophytes.
6. It is formed by germination of a meiospore.	6. It is formed by growth of a zygote.

Terrestrial Amphibians. Bryophytes are called terrestrial amphibians as they require an external layer of water on the soil surface for their existence. The external water is required for (a) dehiscence of antheridia and archegonia (b) swimming of male gametes to archegonia (c) protection from transpiration and hence desiccation as the plant body is not covered by cuticle (d) supply of water to all parts through capillarity in the absence of vascular tissues.

Bryophytes do not Attain Great Heights. Bryophytes seldom achieve great heights. They are small sized. The possible reasons are (a) Absence of roots. (b) Absence of vascular tissues. Materials are transported from cell to cell. (c) Absence of cuticle on the plant body. (d) Absence of mechanical tissue. (e) Requirement of external sheet of water for capillary conduction to all parts and transport of male gametes.

Bryophytes are of three types— hepaticopsida (= hepaticae or liverworts), anthoceropsida (= anthocerotae or hornworts) and bryopsida (= musci or mosses).

Hepaticopsida (Liverworts). The thallus is dorsiventral flattened, dichotomously branched with or without leaf-like appendages having unicellular rhizoids, multicellular scales and completely parasitic sporophyte or sporogonium. They occur on moist shady habitats like marshy ground, damp soil, water banks, deep in the woods, bark of trees, etc. **Examples:** *Riccia, Marchantia, Porella, Pellia, Sphaerocarpos* (Bottle Hepatic).

Marchantia (Fig. 3.11). It is small dorsiventral flattened dichotomously branched thalloid plant with a length of 2–10 cm. Each lobe has an apical notch, a midrib and a dorsal groove. Upper surface bears polygonal areas (areolae), each with a ventilating air pore in the middle. They represent underlying air chambers having assimilatory or photosynthetic filaments. Storage region occurs below it. Ventral surface bears two types of unicellular rhizoids and 4–6 rows of scales or amphigastria (on either side of midrib). The two types of rhizoids are anchoring **smooth walled** and capillary conducting **tuberculate**.

Vegetative reproduction occurs by fragmentation, progressive death of older parts, regeneration, development of adventitious branches and gemmae. Gemmae are small green, biscuit shaped stalked structures which are borne dorsally inside gemma cups. Mature gemmae separate and get dispersed by water and animals and germinate to form new thallus. One gemma may produce two new thalli. Sexually, *Marchantia* is dioecious with sex organs borne on stalked upright receptacles or **gametophores.** Gametophore of male thallus is called **antheridiophore** having a stalk and a 8 lobed male receptacle. Each lobe of the male receptacle has alternate air and antheridial chambers arranged in acropetal fashion. Each antheridial chamber has a single shortly stalked antheridium which produces a number of slightly curved rod shaped biflagellate spermatozoids or antherozoids or sperms. Gametophore of female thallus is called

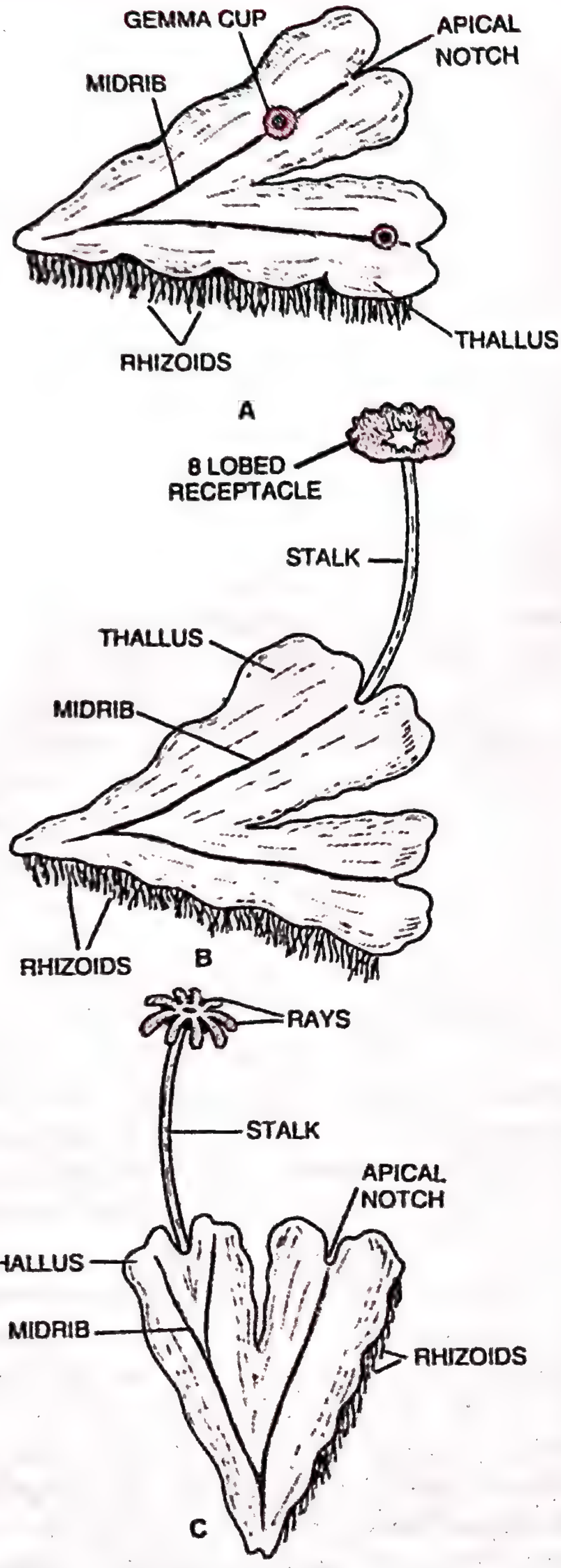


Fig. 3.11. *Marchantia.* A, Vegetative thallus; B, Male thallus; C, Female thallus.

archegoniophore. Its receptacle has nine cylindrical processes or **rays**. The upper surface of female receptacle is convex and bears only air chambers. Each lobe of the receptacle has a patch of hanging archegonia on the under surface with younger archegonia towards the stalk and older archegonia towards the periphery. A two-lipped hanging membranous covering or **perichaetium** occurs around each archegonial patch. The archegonium is shortly stalked flask-shaped structure having a cup-shaped perigynium around the base, a tubular neck and a swollen venter. Neck has six rows of wall cells, four lid cells and 4–6 neck canal cells. Venter has single layered wall, a venter canal cell and an oosphere. Sperms reach the open hanging archegonia by capillarity. They are attracted by proteins and K^+ salts. Fertilization produces zygote which grows to form diploid **sporophyte** or **sporogonium**. Sporogonia are knobbed hanging structures covered by calyptra (from venter wall), perigynium and perichaetium. Each sporophyte or sporogonium has three parts— foot, seta and capsule. Capsule has a single layered jacket. Internally the capsule develops haploid spores and diploid elongated elaters. Seta elongates. Capsule is exposed and begins to dry up. Elaters undergo xerochasic twisting movements. Capsule breaks and spores fall down. They are dispersed by air currents. After falling down on a suitable substratum, each spore germinates to form a new thallus.

Bryopsida (Mosses). They are foliose bryophytes having radial symmetry, multicellular rhizoids with oblique septa and a branched filamentous juvenile stage called protonema. Sex organs occur in clusters over the tips of branches. Sporophyte or sporogonium has a central columella, an assimilatory tissue and acellular peristome for helping in spore dispersal. **Examples** : *Funaria, Polytrichum, Sphagnum.*

Funaria. (Fig. 3.12). It is a common moss of 3–5 cm in height that forms dense patches during rainy season. The plant has a radial symmetry with a once branched axis or stem, a number of spirally arranged leaves and branched colourless multicellular rhizoids. Rhizoids have oblique septa. Main axis functions as male shoot while its branch which is extra axillary in origin, is female shoot. Later on female shoot overtops the male shoot. Leaves are crowded towards the apices. Leaves (phylloids of Koch, 1965) have multilayered midrib and single layered wings. Stem or axis has a single layered epidermis, multilayered cortex and a central cylinder of colourless nearly empty cells called **hydroids**. Both stem and leaves of moss are gametophytic structures as compared to sporophytic structures of vascular plants.

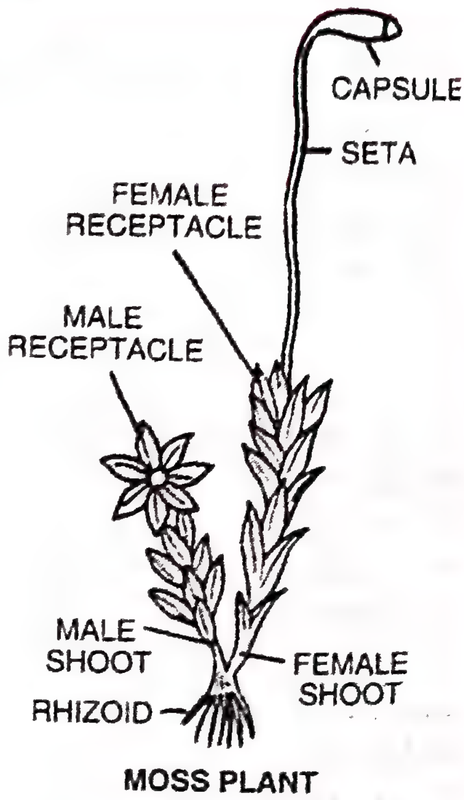


Fig. 3.12. *Funaria* (Moss plant).

Funaria multiplies vegetatively through fragmentation, formation of secondary protonemata, gemmae and tubers. Sex organs occur in male and female receptacles at the tips of male and female shoots respectively. The condition is known as **monoecious** and **autoicous.** The male receptacle is surrounded by a rosette of divergent **perigonial leaves**. It is cup-shaped. Two types of structures occur in male receptacle, club-shaped stalked antheridia and knobbed or capitate green filaments called paraphyses. Female receptacle is covered by whorl of convergent **perichaetial leaves**. It contains stalked archegonia and pointed green filamentous paraphyses.

Sporophyte of *Funaria* has embedded foot, an elongated curved seta and a terminal pyriform asymmetrical capsule. Capsule has three parts— basal photosynthetic apophysis with central nonphotosynthetic columella, middle spore producing theca (with central columella, an air space and small photosynthetic tissue) and upper lid or operculum separated from theca by large celled annulus on the outside and peristome on the inner side. Peristome consists of 32 acellular teeth arranged in two whorls, outer hygroscopic and inner nonhygroscopic. As the spores mature, annulus shrivels and operculum falls down. Outer peristome teeth bend outwardly. As the air shakes the capsule, the spores come out and are dispersed. Spores contain chloroplasts and have the ability to germinate immediately after falling on the suitable substratum. Each produces a filamentous juvenile stage called protonema. Protonema has two types of branches, subterranean nongreen rhizoidal and green epiterranean branches. Buds develop on green prostrate branches which grow to form new moss plants.

Differences between Liverworts and Mosses

Liverworts	*Mosses*
1. The plant body is dorsiventral.	1. The plant body has a radial symmetry.
2. The plants may be thallose or foliose.	2. The plants are always leafy.
3. Leaves, when present, are without a midrib.	3. The leaves generally have a midrib.
4. Branching is generally dichotomous.	4. Branching is lateral and extra-axillary.
5. Rhizoids are unicellular.	5. Rhizoids are multicellular.
6. The plants may bear scales or amphigastria.	6. Scales or amphigastria are absent.
7. Sporogonium has little green tissue.	7. Sporogonium has a sufficient amount of green tissue to make it semi-independent.
8. Seta develops rapidly towards the maturity of spores.	8. Seta grows slowly over a long period and fully developed before the spores mature.
9. Capsule often possesses elaters.	9. Elaters are absent.
10. Peristome teeth are absent.	10. Peristome teeth occur towards the apical region of the capsule.
11. Columella is generally absent.	11. Capsule contains a sterile columella.
12. A protonema stage is absent.	12. A filamentous protonema occurs.

Economic Importance

1. **Prevention of Soil Erosion**. Bryophytes, especially mosses, form dense mats over the soil and prevent soil erosion by running water.

2. **Soil Formation**. Mosses are an important link in plant succession on rocky areas. They take part in building soil in rock crevices formed by lichens. Growth of *Sphagnum* ultimately fills ponds and lakes with soil.

3. **Water Retention**. Dry *Sphagnum* can absorb 18–26 times its weight of water. This characteristic is employed by gardeners to keep seedlings and cut plants moist during transportion and propagation. In older times, *Sphagnum* moss was used in place of absorbent cotton.

4. **Peat**. *Sphagnum* often grows in acidic marshes where there is little decay. The older dead parts of moss and other marshy plants are slowly carbonised, compressed and fossilised over thousands of years to produce a dark spongy mass called **peat**. Peat is dried and compressed and cut to form blocks. The peat blocks are used as fuel. Peat is also a good manure. It overcomes soil alkalinity and increases its water retention as well as aeration.

5. **Other Uses.** Mosses are a good source of animal food in rocky and ice clad areas for mammals, birds and other animals. A decoction of *Polytrichum commune* was employed in removing kidney stones.

VASCULAR PLANTS— Tracheophyta (Gk. *trachia*– wind pipe, *phyton*– plant)

1. They are those plants which possess conducting or vascular tissues, **xylem** and **phloem**. Xylem transports water and minerals while phloem conducts organic food.

2. Vascular plants comprise more than 275,000 living species.

3. They are the most visible green plants around us, so much so that the term 'plants' generally means vascular plants.

4. The plant body is differentiated into true stem, leaves and roots. The roots not only anchor the vascular plants to the soil but also absorb water and minerals from inside the soil. The leaves manufacture organic food by intercepting sunlight and absorbing carbon dioxide from the atmosphere. Stem provides support to leaves and connects the roots with the leaves.

5. On account of anchoring by root and conduction of water, minerals, food, etc. by the vascular tissues, the plants can reach great heights and longevity. *Eucalyptus regnans* (114 m) and *Sequoia sempervirens* (111 m) reach a height of more than 100 m. Plants are known to live for more than 6000 years, *e.g., Macrozamia* (a gymnosperm, 10,000–12,000 years), *Dracaena draco* (Dragon Tree, 8000–10,000 years).

6. Vascular plants are adapted to most diverse environments by modification of their organs.

7. Conspicuous stage or plant body is a sporophyte. Gametophyte is always inconspicuous, living either independently or parasitic over the sporophyte.

8. Accessory spores are absent. Multiplication occurs by vegetative propagation and sexual reproduction. Meiosis occurs inside sporangia associated with leaves. The latter are, therefore, also called sporophylls.

9. An embryo stage is present in the life cycle.

Land animals and most fungi directly or indirectly depend upon vascular plants for their sustenance. They are also the source of food, fibres, fuel, furniture, medicines and a score of other items to human beings.

Reasons for Dominance. Vascular plants dominate land. They have clothed this planet green. The reasons for success and dominance are as follows :

(1) Presence of deep, penetrating and wide-spreading roots which not only anchor the plants but also absorb water and mineral salts from deeper layers of the soil. (2) Covering of aerial parts with water proof material like cutin in living tissue and suberin in dead corky bark. (3) Mechanical tissues present to allow them to rise to great heights. (4) Presence of long distance transport system in the form of vascular tissues. (5) Modification of structure and physiology has occurred to suit various habitats— desert, rocky terrains, moist areas, acid neutral and alkaline soils, warm or cold areas, etc.

Vascular plants are of two types, pteridophytes and seed plants.

PTERIDOPHYTES— Pteridophyta

(Gk. *pteris*– fern, *phyton*– plant)

Pteridophytes are seedless vascular or cryptogamic plants that have sporophytic plant body, inconspicuous gametophytes containing small sessile antheridia and partially embedded archegonia with 4-rowed neck. Vascular tissues developed for the first time in pteridophytes. They occur throughout the plant body.

1. Meiospores are formed inside sporangia by sporic meiosis. Leaves bearing sporangia are called sporophylls.

2. Spores may be similar (homosporous) as in majority of pteridophytes *e.g., Pteris Adiantum.* A few plants are heterosporous, *i.e.,* with two types of spores, microspores and megaspores, *e.g., Selaginella, Salvinia, Marsilea.*

3. Sperms are bi or multi-flagellate. They require an external supply of water to reach archegonia.

4. Heteromorphic or heterologous alternation of generations is present in the life cycle.

5. Pteridophytes generally occur in cool, damp, shady places. Some extend to sandy soils. *Azolla, Salvinia, Marsilea* are aquatic.

Examples : *Selaginella, Adiantum, Dryopteris, Equisetum* (Horse–tail) *Salvinia.*

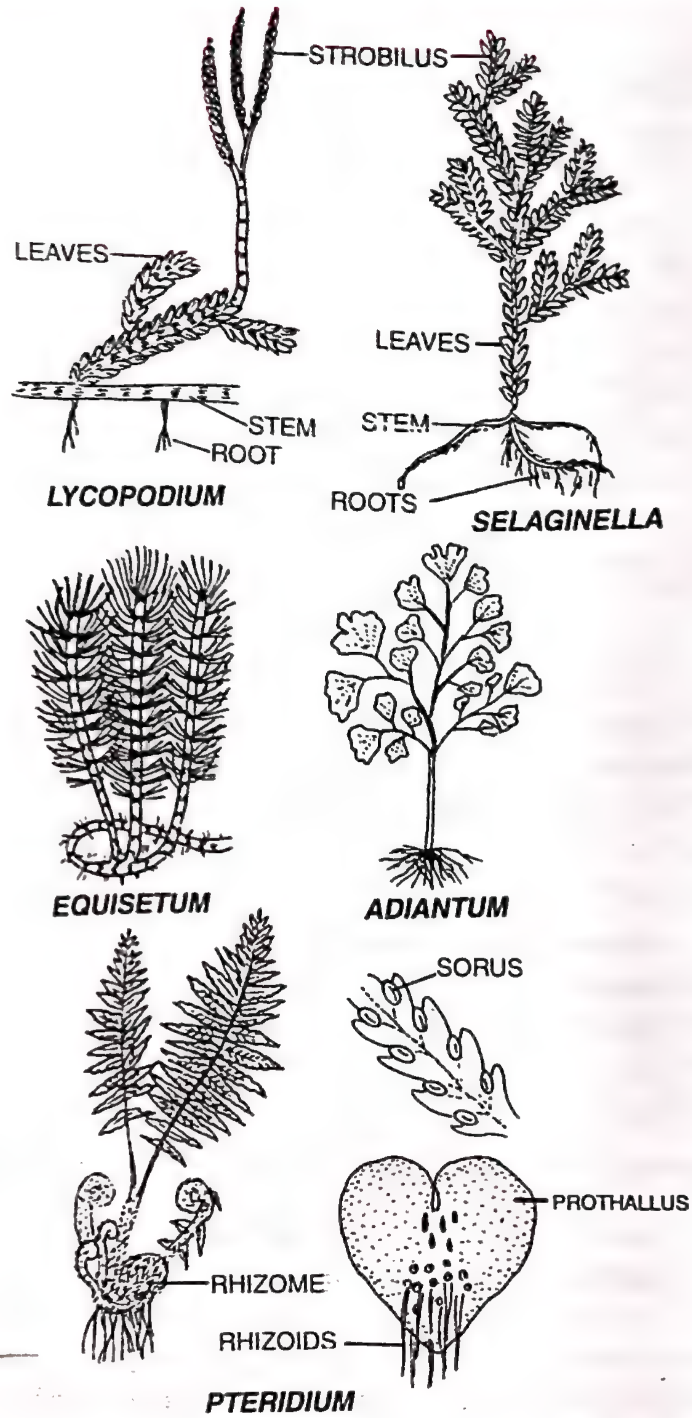


Fig. 3.13. Common Pteridophytes.

Economic Importance

(1) **Food.** Like other plants, pteridophytes constitute a good source of food to animals. Sporocarps of *Marsilea*, a water fern, yield starch that is cooked and eaten by certain tribals. (2) **Soil Binding.** By their growth pteridophytes bind the soil even along hill slopes. The soil is protected from erosion. (3) **Scouring.** *Equisetum* stems have been used in scouring (cleaning of utensils) and polishing of metals. *Equisetum* species are, therefore, also called scouring rushes. (4) **Nitrogen Fixation.** *Azolla* (a water fern) has a symbiotic association with nitrogen fixing cyanobacterium *Anabaena azollae*. It is inoculated to paddy fields to function as biofertilizer. (5) **Medicines.** An anthelmintic drug is obtained from rhizomes of *Dryopteris* (Male Shield Fern). (6) **Ornamentals.** Ferns are grown as ornamental plants for their delicate and graceful leaves.

Differences between Bryophytes and Pteridophytes	
Bryophytes	*Pteridophytes*
1. Plant body is gametophyte.	1. Plant body is sporophyte.
2. Vascular tissues are absent.	2. Vascular tissues are present.
3. Sporophyte is parasitic over gametophyte.	3. Both sporophyte and gametophyte are independent.
4. Plant body can be thallose or foliose.	4. Plant body is differentiated into stem, leaves and roots.
5. True stem and leaves are absent.	5. Plants possess true stem and leaves.
6. Roots are absent. Instead, rhizoids occur.	6. Roots are present.
7. Haploid or gametophytic phase is longer lived while sporophytic phase is shorter lived.	7. Diploid or sporophytic phase is longer lived while gametophytic phase is shorter lived.
8. Antheridium is stalked.	8. Antheridium is sessile.
9. Archegonium is commonly exposed.	9. Archegonium is partially embedded.
10. Neck of archegonium is formed of 5-6 rows of cells.	10. Neck of archegonium has four rows of cells.

They have four classes— Psilopsida, Lycopsida, Sphenopsida and Filicopsida.

Psilopsida (Psilophytes). They are the most primitive vascular plants. Roots are absent. Instead rhizoids occur. Stem is dichotomously branched. It has two parts, aerial and rhizomatous. Aerial stems are green and photosynthetic. Leaves may be present or absent. Sporangia develop over the aerial stem either terminally or axially. Two primitive forms found in fossil state are *Cooksonia* (silurian) and *Rhynia* (devonian). Living forms are *Psilotum* and *Tmesipterus*.

Lycopsida (Lycopods). Primitive vascular plants which have differentiation of roots, stems and leaves. Leaves are microphyllous, *i.e.*, do not produce a leaf gap in vascular strand of the stem. Sporophylls form sporangiferous spikes or strobili. Sporangia develop either axially or adaxially. Branching is dichotmous or pseudodichotmous. **Examples** : *Lycopodium, Selaginella*.

Selaginella (Club Moss, Spike Moss, Fig. 3.14)

It is a trailing, hanging or erect evergreen lycopod. Some species roll up in dry season to form brown balls (capitose habit) which may get uprooted and dispersed. They turn green with the availability of water. Such species are called **resurrection plants**, *e.g., S. bryopteris,* (Sanjivani booti), *S. lepidophylla*. Stem is dichotomously branched in erect and hanging species, *e.g., S. selaginelloides*. It is monopodial pseudodichotomous in trailing forms, *e.g., S. chrysocaulos*. Leaves are simple, sessile and microphyllous. Each one bears a small scale called **ligule** on the basal adaxial surface. Because of it, leaves of *Selaginella* are called **ligulate**. Leaves are isophyllous and

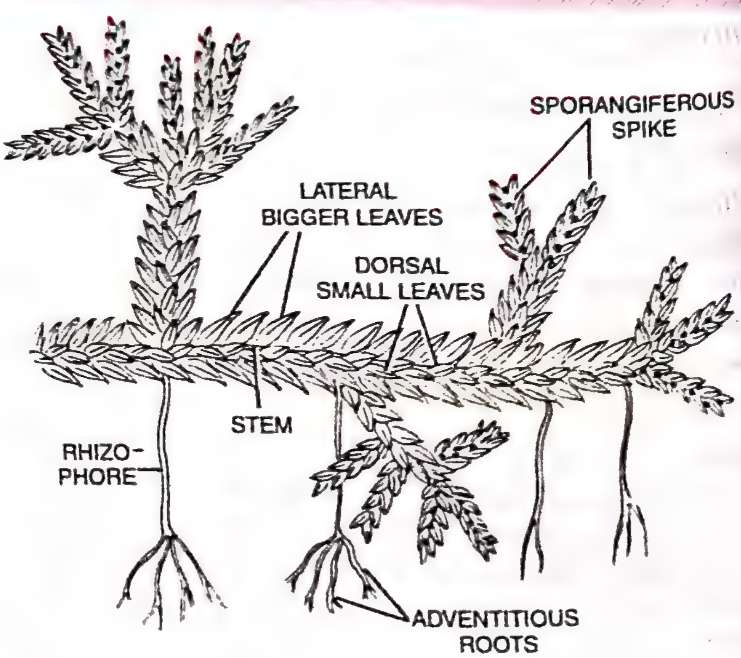


Fig. 3.14. A, *Selaginella*.

spirally arranged in subgenus *Homoeophyllum* having erect or hanging species, *e.g.*, *S. selaginelloides*. They are dimorphic forming four rows in opposite decussate manner in subgenus *Heterophyllum*, *e.g.*, *S. kraussiana*. Here there are two rows of small dorsal and two rows of large lateral leaves with dorsal and lateral of one side alternating while dorsal and lateral leaves come to lie opposite at one point. **Roots** are adventitious. They develop either directly from stem or at the top of a special leaflet, positively geotropic structures called **rhizophores**. Rhizophores are peculiar to *Selaginella*. They develop from either base of the stem or region of stem forkings.

Vegetative reproduction occurs by fragmentation, fleshy buds (bulbils) and tubers. *Selaginella* produces two types of spores, microspores and megaspores. The phenomenon is called **heterospory**. Their sporophylls are aggregated at the tips of stem branches to form **strobili** or **sporangiferous spikes**. Sporangia develop in the axil of sporophylls. Megasporangia are larger, whitish or yellowish often lobed with 1–4 haploid megaspores. Microsporangia are smaller, yellowish-reddish globular-reniform structures which produce a large number of haploid microspores. Spores begin to develop precociously inside the sporangia. It is completed later on.

Seed Habit of Selaginella. *Selaginella* shows traits which resemble the characteristics essential for formation of seed. They are collectively called seed habit of *Selaginella*. (i) Heterospory. (ii) Formation of two types of gametophytes, male and female. (iii) Gametophytes are nutritionally dependent on parent sporophyte. (iv) Gametophytes show precocious development which is also endospermic. (v) Only one megaspore mother cell is functional. (vi) In some species, a single megaspore develops into a megasporangium, *e.g.*, *S. monospora*. (vii) In some species, the megaspore is not shed but develops completely inside partially opened megasporangia, *e.g.*, *S. apus*, *S. rupestris*. Microspores reach there and form male gametophyte. Fertilization and development of embryo also occur there. However, seed formation does not occur. (viii) In *S. yemensis* the megasporangium is surrounded by integument.

Sphenopsida (Horsetails). Stem is jointed and ribbed with leaves and branches borne in whorls. Sporangia develop on peltate sporangiophores aggregated into terminal strobili. Plants are homosporous. Spermatozoids are multiflagellate. One living genus called *Equisetum*.

Equisetum (Horsetail, Scouring Rush, Fig. 3.15)

Plant body is differentiated into stem, leaves and roots. Height is from a few centimetres to several metres. Stem has two components, underground rhizome and upright aerial branches. Stems are jointed. Internodes possess longitudinal ridges or ribs and hollow interiors. Nodes possess a whorl of scale leaves. Function of photosynthesis is carried out by green aerial stem branches. Intercalary meristem occurs above the nodes. In rhizome some of the branch primordia develop into tubers, *e.g.*, *E. arvense*. Due to presence of intercalary meristems, internodes can be easily pulled out as pipes.

Adventitious roots develop in whorls over the nodes of rhizome. **Xylem has xylem vessels**. Aerial branches develop terminal strobili. In *E. arvense*, there are two types of aerial branches, green sterile and brown fertile. Terminal strobili occur only on fertile branches.

Pteropsida (Ferns). The most conspicuous of the pteridophytes are the **ferns**. Ferns are pteridophytes that bear sporangia in sori on the leaves which show circinate ptyxis in the young condition.

1. The stem is underground **rhizome** in most of the ferns. Some primitive ferns have

above-ground stem with tree-like habit. They are called **tree ferns**, *e.g.*, *Cyathaea*, *Celeotium*. A tree fern is like a small palm. It may reach a maximum height of 20 m.

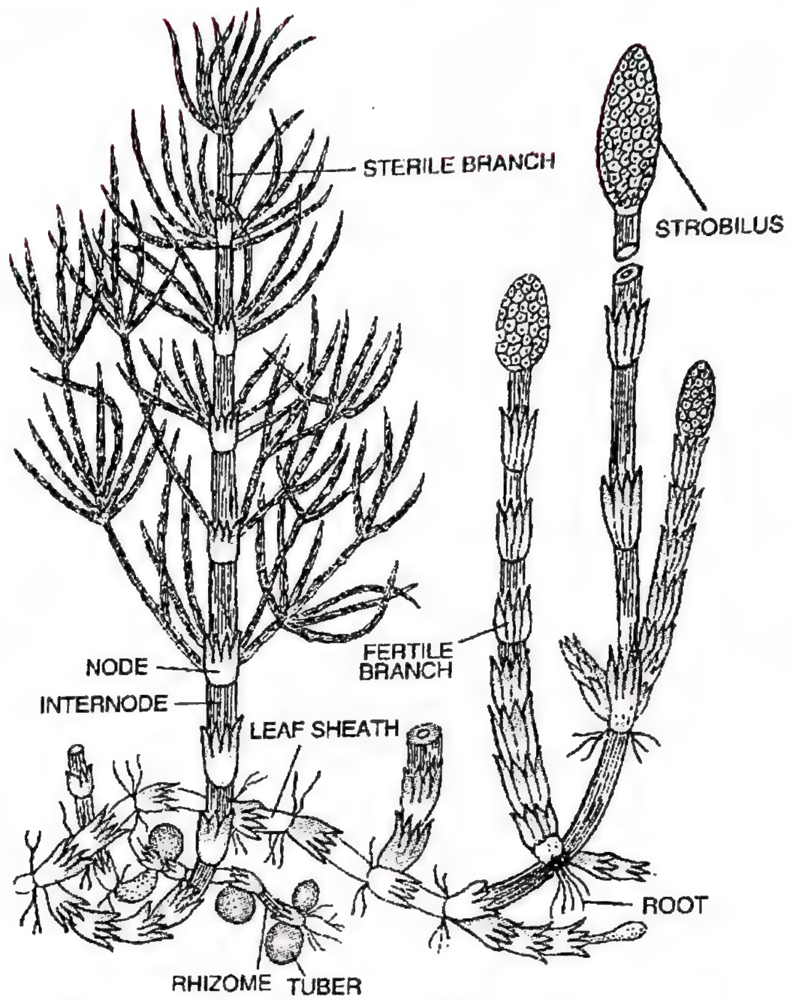


Fig. 3.15. Sporophytic plant body of *Equisetum arvense* showing underground rhizome bearing roots, fertile and sterile aerial branches and tubers.

2. Leaves are large and are called **fronds**. They are often graceful. Leaves may be **simple** or **pinnately compound**. In a pinnately compound leaf, the lamina is divided laterally into leaflets. It may be **unipinnate** (once pinnate, leaflets borne directly on rachis which is continuation of petiole), **bipinnate** (twice pinnate, leaflets borne on primary branches of rachis) or **tripinnate** (thrice pinnate, leaflets borne on tertiary axes or secondary branches of rachis).

3. Leaves or their leaflets show **open furcate venation** in which veins branch dichotomously without forming interconnections.

4. Younger parts of stem, young leaves, petiole and rachis of mature leaves possess hairs or scales called **ramenta**. Ramenta protect them from mechanical injury and desiccation.

5. The gametophyte is thalloid and called **prothallus**. Prothallus is the term used for free living gametophyte having sex organs. It develops a young sporophytic plant body from inside the female sex organ.

6. The life cycle has a regular alternation of a dominant sporophyte and an inconspicuous gametophyte. This is called **heterologous** or **heteromorphic alternation of generations**.

Ophioglossum reticulatum (Adders tongue fern) has maximum number of chromosomes (2n = 1262).

Fern (Fig. 3.16)

Adiantum (Maiden Hair Fern) and *Dryopteris* (Male Shield Fern) are the two common ferns that are found in moist shady places in tropical, subtropical and temperate areas. *Adiantum* is also observed to occur under bridges, water courses and walls of old wells. Plant body is a **perennial** independently living **evergreen sporophyte** having vascular tissues. It is differentiated into stem, leaves and roots. Roots are adventitious. Stem is an underground dark brown **rhizome**. The large aerial leaves or **fronds** develop acropetally in spirals from the upper surface of the rhizome. The young leaves show **circinate ptyxis.** Persistent **leaf bases** of the dead leaves are found in older parts of rhizome.

Petioles are shining, smooth and blackish in *Adiantum* (hence Maiden Hair Fern). Leaf base possesses an adventitious bud in case of *Dryopteris*. Lamina is pinnately divided. It is **unipinnate** in *Adiantum caudatum*, **bipinnate** in *Dryopteris* (incompletely or completely) and *A. capillus-veneris* and **tripinnate** in *A. cuneatum*. Venation is **furcate** or dichotomously divided. In *Dryopteris*, a leaflet receives a single midrib which gives rise to lateral veins showing dichotomous divisions. Venation is, therefore, furcate and pinnate. In *Adiantum*, a leaflet receives a number of veins which spread like a fan, dividing dichotomously in the way.

The young leaves, young parts of rhizome, petiole and rachis of mature leaves are covered over by brown to black scales called **paleae** or **ramenta**.

The fern multiplies vegetatively by **fragmentation** of rhizome and development of **adventitious buds**. In *Dryopteris* the adventitious bud

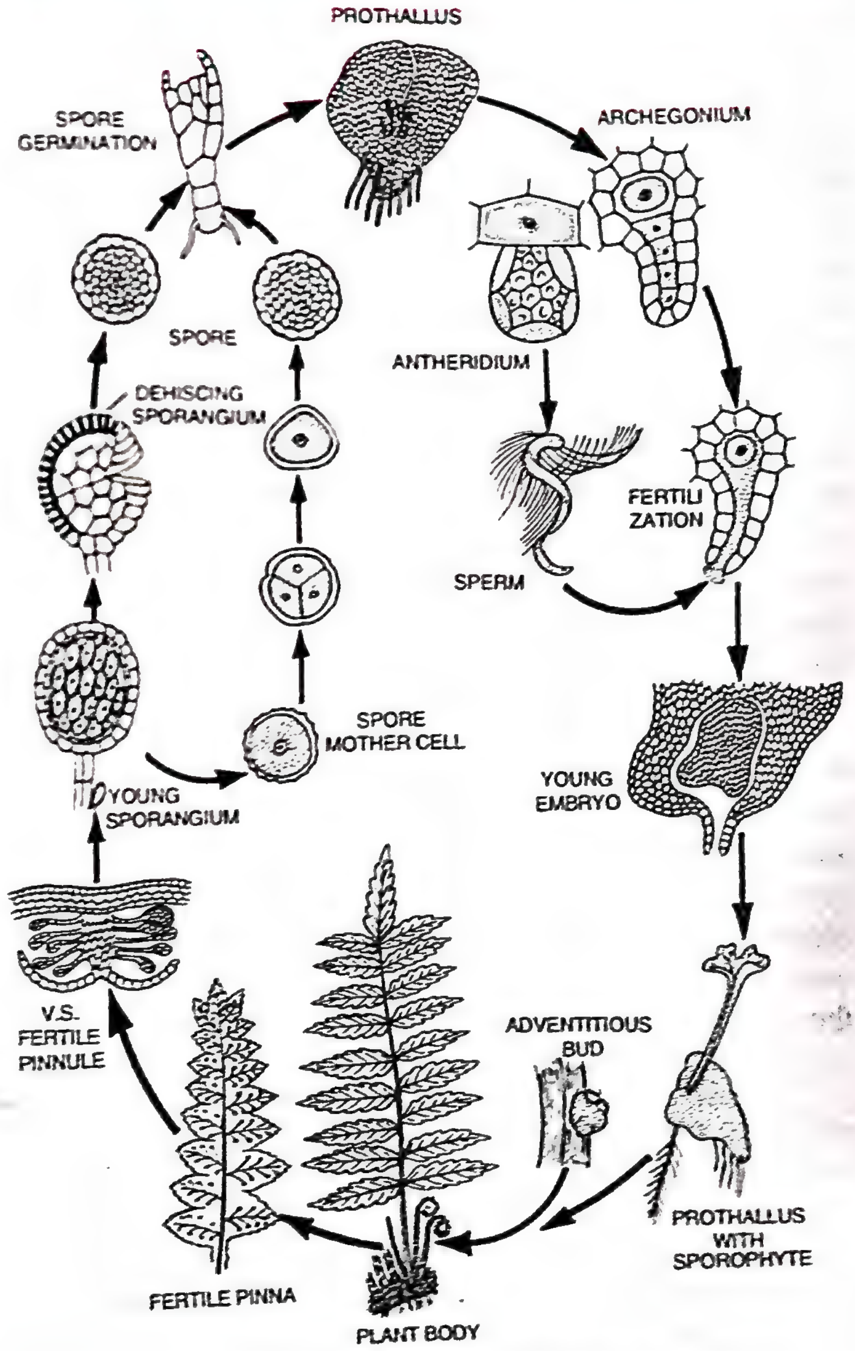


Fig. 3.16. Diagrammatic diplohaplontic life cycle of *Dryopteris* fern.

present at leaf base separates and grows into a new plant. In *Adiantum caudatum* and a few other species, adventitious buds develop at leaf tips. When such leaf tips happen to touch the soil, they form new plants. The process helps in spreading the fern over a large area. Because of this reason *A. caudatum* is also called **walking fern**.

Leaflets of a mature leaf bear yellowish brown spots having clusters of sporangia called **sori**. The leaflets and leaves having sori or sporangia are called **sporophylls**. In *Adiantum*, the sori are borne submarginally at the distal end on the under surface of the leaflets. The margin of the leaflet is reflexed to cover sorus. The reflexed margin is known as **false indusium**. In *Dryopteris*, the sori develop in two rows, one on either side of the midrib. Each row contains 4–6 sori except in smaller leaflets which may have 1–2 sori or can be sterile. Each sorus is covered by a membranous sheath of its own. This covering is called **true indusium**. The covered sori of *Dryopteris* are kidney-shaped in outline. This has given the name of **male shield fern** to *Dryopteris*.

A sorus consists of parenchymatous cushion or **placenta**. The placenta bears a number of stalked biconvex **sporangia**. In each sporangium there is a single layered jacket that encloses 12–16 diploid spore mother cells. A marginal row of jacket cells are differentially thickened to form **annulus**. The remaining marginal cells constitute **stomium**. The diploid spore mother cells divide meiotically to form haploid **spores**. With the maturity of spores, the indusium shrivels. The exposed sporangia dehisce in the region of stomium due to differential contraction of annulus. The spores are thrown away. They are dispersed by air currents.

After falling on a suitable soil, each spore germinates to form a flat cordate, green, thalloid, non vascular, free living, inconspicuous, small, multicellular, independent gametophyte called **prothallus**. The prothallus is monoecious, that is, it bears both the types of sex organs, male antheridia and female archegonia. They are borne ventrally. Antheridia occur in the area of rhizoids while archegonia are borne behind the apical notch in an area called apical cushion. Antheridium is hemispherical in outline. It has a 3–celled jacket and about 32 sperm mother cells. The sperms are multiflagellate (= multiciliate) and spirally twisted.

Archegonium is flask-shaped in outline. It has an embedded venter and a projecting neck. Neck has 4–rowed wall which encloses a single binucleate neck canal cell. The venter contains a single venter canal cell and an oosphere. In the mature state, the venter canal cell and the neck canal cells gelatinise. Sperms are attracted (chemotaxy) to the opened archegonia by malic acid present in their mucilage. A sperm fuses with an oosphere to form a diploid oospore. The oospore gives rise to an embryo which grows to form the fern plant. The prothallus dies meanwhile.

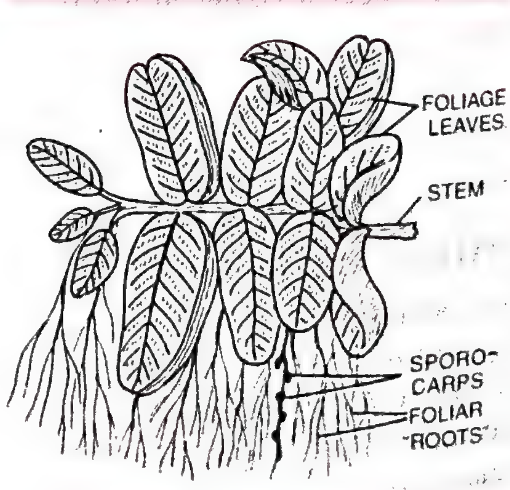


Fig. 3.17. Salvinia.

Salvinia (Fig. 3.17). It is an aquatic fern with both annual (*e.g., S. nutans*) and perennial species (*e.g., S. molesta*). It is called sorrow of Kashmir. The plant body consists of a floating stem bearing two rows of large green hairy leaves on the upper surface and highly branched leaf roots on the lower surface. The roots act as balancers. Hair protect leaves from wetting at places. The plant bears sporocarps sympodially. Sporocarps are sporangia bearing bodies. It is heterosporous.

Differences between Homosporous and Heteroporous Pteridophytes

Homosporous Pteridophytes	*Heterosporous Pteridophytes*
1. All the sporangia are similar.	1. The sporangia are of two types, macro and microsporangia.
2. The spores are of one type.	2. The spores are of two types, larger megaspores and smaller microspores.
3. Gametophytes are of one type. There is no specialization.	3. Gametophytes are of two types, male and female. Both are specialized to perform their function.
4. It has no evolutionary significance.	4. It has an evolutionary significance as heterospory is prerequiste to pollination and seed formation.

SEED PLANTS— Spermatophyta (Gk. *sperma*– seed, *phyton*– plant)

1. They comprise over 250,000 vascular plants.
2. After sexual reproduction, the plants produce seeds for dispersal and multiplication. The seeds are dormant and can easily pass through unfavourable conditions.
3. The plant body belongs to sporophytic generation.
4. The sporophytic plant body is differentiated into true stem, leaves and roots.
5. Plants show **heterospory** or two types of meiospores, microspores and megaspores. They are produced in two types of sporangia, microsporangia (pollen sacs) and megasporangia.
6. The two types of sporangia are borne on two distinct sporophylls called **microsporophylls** and **megasporophylls**. They are modified variously in seed plants.
7. Megasporangia are integumented and are called **ovules**.
8. Microspores or pollen grains reach the ovules in a process of pollination.
9. The gametophytes are completely parasitic.
10. Sex organs are multicellular but there is a reduction in their constituents.
11. An external supply of water is not required for fertilization.
12. Fertilization occurs with the help of a tube formed by male gametophyte. It is called **pollen tube**. Such a mode of fertilization is called **siphonogamy**.
13. An embryo stage is formed after fertilization. It stops growth temporarily after some time.
14. The ripened ovule having a dormant embryo is shed as a seed.

Seed plants are divided into two groups, gymnosperms (*e.g.*, *Pinus*) and angiosperms (*e.g.*, Wheat, *Eucalyptus*, Mango).

Development of Seed Habit

Development of seed habit occurred in now extinct **pteridosperms** or cycadofilicales, a group intermediate between cycads and ferns. The habit made the seed plants independent of the requirement of external sources of water at the time of fertilisation. In seedless vascular plants, the gametophyte must develop on moist soil with a thin sheet of water. The latter is required for the swimming of sperms for reaching the female sex organs. As a result, seedless vascular plants could never become true land plants and are popularly called amphibians among plants.

There are several requirements for development of seed habit :

1. Development of heterospory or formation of two types of spores, smaller male or microspores and larger female or megaspores. The two types of spores form two different types of gametophytes, male and female.

2. The megasporangium developed an integument like covering with a pore or micropyle.

3. In a megasporangium only one megaspore mother cell remained functional. The other cells did not form mother cells but remained sterile.

4. The single megaspore mother cell formed 4-haploid megaspores. Out of them, three degenerated and only one remained functional.

5. The functional megaspore started forming the female gametophyte inside the integumented megasporangium. It is known as precocious development.

6. The megaspore was never shed. It stopped developing an impermeable covering over it. As a result the female gametophyte being formed by it continued to receive nourishment from the sterile or nucellar cells. The female gametophyte, therefore, reached full maturity and formed sex organs there.

7. Development of pollination or transfer of microspore to the megasporangium or receptor area of the megasporophyll.

8. Growth of male gametophyte near the megasporangium.

9. Formation of pollen tube for carrying the male gametes into the interior of megasporangium where the female sex organs are present. Fertilisation performed with help of pollen tube is called siphonogamy.

10. Development of embryo inside the female gametophyte enclosed in megasporangium.

11. Temporary suspension of growth of embryo and conversion of integumented megasporangium or ovule into a seed.

12. Shedding of the seed.

13. Resumption of growth by the embryo after the seed reaches area favourable for growth.

Three Generations Locked in Seed

Seed develops from an ovule or megasporangium. An ovule consists of integument and nucellus. Both of them are diploid or belong to sporophytic generations. In seed, the integument persists as a seed coat/seed coats. Parts of nucellus may also persist.

In the centre of megasporangium or nucellus part of ovule develops a haploid megaspore which grows into haploid female gametophyte. The female gametophyte partly eats away the surrounding nucellus. The female gametophyte develops an egg or oospore. The latter is fertilised by a male gamete brought by a pollen tube to form diploid zygote ($2n$). The zygote develops into an embryo or new sporophyte. The embryo ($2n$) is surrounded by female gametophyte (n), the latter by seed coat ($2n$). Therefore, a seed contains three generations locked one within another:

(a) Parent sporophyte in the form of seed coat/coats and persistent nucellus,

(b) Female gametophyte which stores food, and

(c) Future sporophyte in the form of embryo.

Adaptations to Land. Seed plants are the most successful of all the land plants. The different adaptations to terrestrial life are as follows :

(i) Development of pollination or carrying the microspores to the megasporophylls.

(ii) Non-requirement of external supply of water for fertilisation. This has been made possible through the development of pollen tube for carrying the sperms to the female gamete.

(iii) (a) Transformation of megasporangium into an ovule. (b) Formation of only one megaspore mother cell in an ovule. (c) Formation of only one megaspore in a megasporangium. (d) Fertilisation of egg in ovule. (e) Production of embryo in the ovule.

(iv) Temporary suspension of growth of the embryo in the ovule and transformation of ovule into a seed for dispersal.

(v) Other characters of seed plants which have helped them to dominate the land are (a) Extensive root system for anchoring and absorption of water as well as minerals. (b) Development of mechanical tissues. (c) Presence of vascular tissues for long distance transport of sap and food materials. (d) Development of cambium for secondary growth. (e) Presence of bark for protection.

GYMNOSPERMS (Gk. *gymnos*– naked, *sperma*– seed)

(Plants with Naked Seeds or Seed Plants Without Flowers)

Gymnosperms are those seed plants in which the seeds remain exposed over the surface of the megasporophylls because the latter are not folded to form pistils.

1. Gymnosperms are a small group of seed plants which are represented by only 900 living species.

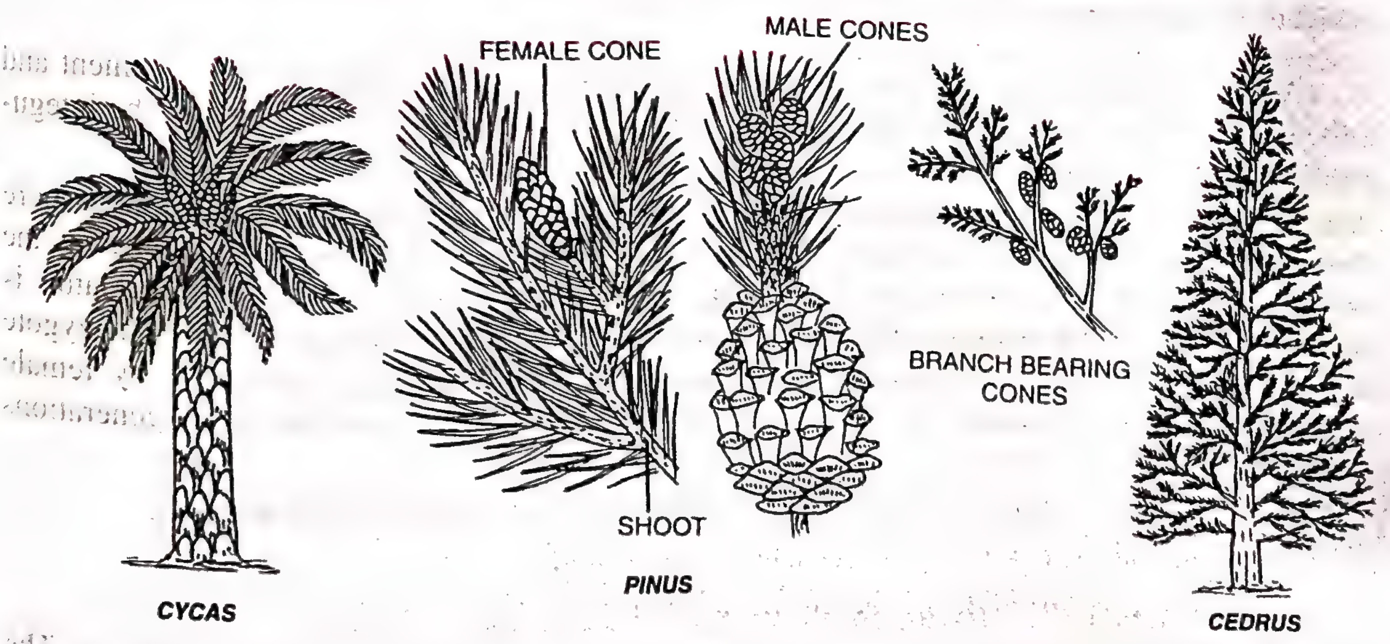


Fig. 3.18. Some Gymnosperms.

2. All gymnosperms are **perennial** and woody, forming either bushes or trees. Some of these are very large and live for thousands of years, *e.g., Sequoia sempervirens* (tallest gymnosperm of 111.6 m) *Zamia pygmia* is smallest (26 cm).

3. Two types of sporophylls, microsporophylls and megasporophylls are usually aggregated to form distinct cones or strobili, pollen cones (male cones) and seed cones (female cones) respectively.

4. Seeds do not occur inside a fruit. They are **naked.**

5. Female gametophyte contains archegonia.

6. Pollination is direct as a stigma is absent and the pollen grains directly reach the micropylar ends of ovules. Pollination is usually accomplished by wind (anemophily).

7. Male gametophyte produces only two male gametes or sperms. Generally one of them is functional.

8. An external water is not required for transport of male gametes. Instead, a pollen tube is formed by the male gametophyte for effecting fertilization (siphonogamy).

9. Seeds contain a food laden tissue or **endosperm** for future growth of embryo into seedling. The tissue represents the female gametophyte.

10. Like pteridophytes, xylem does not possess vessels except in some gnetophytes. Phloem is without companion cells and sieve tubes. Sieve cells are not arranged end to end in rows.

Living gymnosperms are divided into four groups— Cycadopsida, Ginkgopsida, Coniferopsida and Gnetopsida. Ginkgopsida is represented by **maiden hair tree** (*Ginkgo biloba*). Gnetopsida contains *Gnetum, Ephedra* and *Welwitschia*. These are nearer to flowering plants in having flower like arrangement of sporophylls and possessing primitive vessels in xylem. Plants of cycadopsida and coniferopsida are commonly called **cycads** and **conifers** respectively.

Cycads. It is smaller group of gymnosperms which have palm-like habit and fern-like foliage. Leaf bases are often persistent. In stem the vascular tissues constitute only a narrow patch though secondary growth occurs. Plants are **dioecious**, that is, microsporophylls and megasporophylls develop on separate plants. The sporophylls are aggregated to produce strobili or cones (exception megasporophylls of *Cycas*). Megasporophylls are often leaf-like and possess ramenta. Sperms are motile. The plants are mostly xerophytic and occur in warm weather. Their population is, however, decreasing due to extension of agriculture and severe competition from xerophytic angiosperms. Cycads are grown for their ornamental appeal, *e.g., Cycas circinalis, C. revoluta.*

Cycas (Fig. 3.18)

Cycas is also called **living fossil** because it possesses a number of characters of extinct pteridosperms and cycads. The gymnosperm is an evergreen small palm-like or tree-fern like sporophyte that occurs in some tropical and subtropical areas. It reaches a

height of 0.4 m to 20.0 m. *Cycas* has an unbranched columnar stem (rarely branched) which is covered by spiral bands of **peristent** rhomboidal **leaf bases**. The top bears a crown of leaves. Leaves are of two types, large green foliage and small brownish scale leaves. Scale leaves develop in spiral rows alternating with foliage leaves. They are covered with ramental hair. Foliage leaves are large (1–3 m), petiolate and unipinnate. Base is broad. Petiole bears two rows of spines. Petiole continues into rachis. Rachis has two lateral grooves from which arise 50–200 pairs of sessile, linear-lanceolate pinnae or leaflets. Leaflet apex is spiny while the margin can be straight or revolute (*e.g., C. revoluta, C. beddomei*). Young leaves show **circinate ptyxis**. Roots are of two types, normal and coralloid. **Coralloid** roots are irregular, negatively geotropic, dichotomously branched coral like roots which do not possess root hairs and root caps. Coralloid roots have a symbiotic association with blue-green algae like *Nostoc* and *Anabaena* species. Sago grains occur in the stem cortex.

Vegetative reproduction occurs by fleshy **bulbils** which arise adventitiously in the crevices amongst persistent leaf bases. Sexually *Cycas* is **dioecious** with distinct male and female plants. The plants bear terminal **cones**. Male cone is oval, thick, 20–80 cm long stalked structure which replaces the growing point of the plant. Further growth of male plant is carried out by a lateral bud, so that stem axis of male plant is sympodial. Male cone has a number of densely crowded spirally arranged **microsporophylls**. Each microsporophyll has a flat fertile proximal region and a distal bent sterile region or apophysis. The fertile region bears a number of microsporangia or pollen sacs arranged in sori. Microspores or pollen grains are boat-shaped.

Female cone is loose. It consists of a rosette of brown megasporophylls. Each megasporophyll bears 2–12 reddish ovules in the middle fertile part. The terminal sterile part may show remains of foliar structure. Ovules of *Cycas* are the largest, 6–7 cm in diameter. Similarly, egg or oosphere is the largest in plant kingdom.

Pollination is anemophilous. Before pollination, pollen grain develops three cells— prothallial cell, generative cell and tube cell. Pollination brings pollen grains inside the ovules. The tube cell grows and forms a pollen tube. Pollen tube is haustorial in function in *Cycas*. Generative cell divides into sterile stalk cell and large fertile body cell. Body cell produces two sperm mother cells. The sperms of *Cycas* (upto 300 μm) are the **largest** in the biological world. They are top-shaped with a number of **flagella** present in 5–6 grooves on the pointed end. Seed is oval to rounded orange-red structure which generally has a fleshy outer sarcotesta for attracting birds.

Conifers. They comprise more than 500 living species of cone bearing gymnosperms which have withstood competition from angiosperms. The plants are evergreen with dense and massive vascular tissues and non-motile gametes. Conifers are usually **monoecious**. Cones or strobili are compact and woody. Both the types of cones are borne on the same plant. Unlike cycads, they are not produced on the tips of main branches.

Leaves are mostly borne on the dwarf branches. The dwarf branches have a limited or definite growth. Leaves have thick cuticle and sunken stomata. They are needle like (*e.g., Pinus*), small flat and leathery (*e.g., Araucaria*) or scale like (*e.g., Thuja*).

Araucaria (a tall and majestic conifer of South America, New Zealand and East Australia) grows in warm weather in plains as well as foot hills. Other conifers form vast and dominant woodlands in mostly north temperate regions of Europe, Asia, North America, etc. They are abundant on the upper timber-line zone of mountains including the Himalayas, *e.g.*, *Pinus* (Pine), *Cedrus* (Cedar), *Picea* (Spruce), *Abies* (Fir), *Juniperus* (Juniper), *Thuja*, *Larix*, *Cupressus*. Conifers are dominant constituents of north temperate flora due to the following reasons :

1. In the temperate areas, conifers have an advantage over angiospermic trees. While the angiospermic trees shed their leaves during autumn-winter period, the conifers remain evergreen. They continue to manufacture their food during this period when other plants are in a state of hibernation because of the absence of leaves.

2. Conifers have a number of xerophytic characteristics which help in conserving water. They are, thus, able to tide over the winter period when the soil becomes frozen and water availability is very little. Mycorrhizae allow them to get water and minerals.

3. Enzymes of conifers are functional even at –35°C at which temperature they become inactivated in other plants.

Pinus (Fig. 3.18)

Pinus or Pine is a coniferous gymnosperm. It is a large tree having pyramidal or excurrent shape like a "christmas tree". The plant body is a sporophyte having stem, leaves and roots. The main stem is straight. It may reach a height of 10–50 metres. The main stem shows monopodial branching. Stem branches are of two types, long and dwarf. The dwarf branches possess 1–5 needle-like foliage leaves which are surrounded at the base by a sheath of scale leaves. *Pinus* has an horizontally spreading tap root system with peg-like downwardly directed roots present at intervals. Finer roots are of two types— normal (with root hairs and root cap) and mycorrhizal. The mycorrhizal roots occur near the soil surface. They are devoid of root hairs and root cap.

The sporophytic plant body does not multiply vegetatively. It produces micro- and megasporophylls in two types of cones, male and female. Male or pollen cones occur in clusters subterminally on lower long branches. Each male cone has a short stalk, a central axis and a number of spirally arranged microsporophylls. A microsporophyll bears two oblong, parallel microsporangia on its lower surface. Pollen grains are dispersed by air currents. They form yellow clouds in the pine forests. A pollen grain has two air sacs or wings for making it light.

The female or seed cones develop in groups of 2–6 on upper long branches of the tree. Each female cone has a long stalk and a central axis on which are borne a number of spirally arranged paired scales. The lower of the pair is called bract scale while the upper scale is ovuliferous scale or megasporophyll. The ovuliferous scale bears two ovules towards the basal region on the upper side.

The female cones open in the year of their formation for pollination. Pollination is anemophillous (by air) and direct. After fertilization the ovule matures into a seed. Part of the upper surface of the ovuliferous scale is peeled off alongwith the seed to form its wing. A female cone takes about 26 months for reaching maturity. It then opens to release winged seeds which are dispersed by air. After falling on a suitable soil, each seed gives rise to a new plant.

Ginkgoales

They are primitive gymnosperms which possess deciduous leaves with furcate venation, two types of branches, unisexual plant, catkin like male inflorescence with each

microsporangiosphore having 2–12 microsporangia, multiciliate male gametes and clusters of megasporangiate structures each with a long stalk and two ovules. Ginkgoales are represented by a single species, *Ginkgo biloba*.

Ginkgo biloba. *Ginkgo biloba* (Fig. 3.19) has not changed for the last several millions of years since its appearance in *triassic period*. It is also called **living fossil**. The plant has survived due to interest shown by horticulturists. It has natural immunity to several plant diseases. The plant is a tall tree of upto 30m height. Leaves are fan-shaped. They are deeply bilobed on long shoots. The leaves are entire or sinuate on dwarf shoots. Leaves possess furcate venation. *Ginkgo* is dioecious like cycads. Dwarf shoots of female plants bear distinct megasporangiate structures. Each has a stalk that ends into two ovules. Ovule has a 3-layered integument, micropyle and a pollen chamber. Endosperm of roasted seed is edible. However, horticulturists prefer to grow only male plants as the female plants give unpleasant smell.

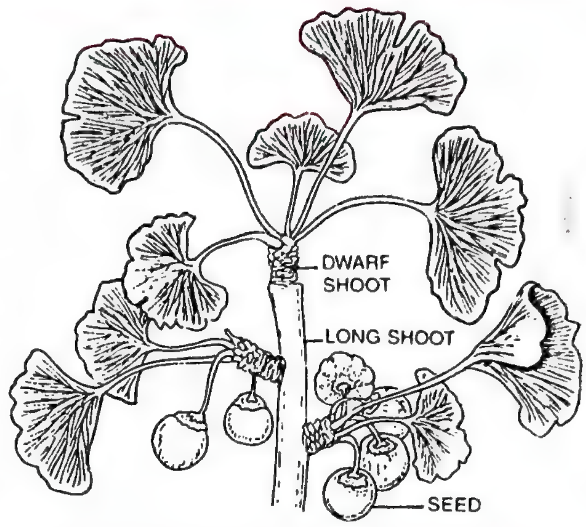


Fig. 3.19. Ginkgo– Shoot bearing seeds.

Economic Importance of Gymnosperms

1. **Edible Seeds**. Seeds of *Pinus gerardiana* are edible. They are eaten after roasting.
2. **Timber**. Gymnosperms possess softwood. The same is used in preparation of light furniture, plywood, packing cases, match sticks, railway sleepers, etc.
3. **Paper**. A number of gymnosperm woods are used in the manufacture of paper. They include *Picea, Pinus, Larix* and *Abies*.
4. **Fibre Boards**. Needles of *Pinus* and other conifers are used in making fibre boards that are used in making packing cases.
5. **Linoleum**. Saw dust is employed in making linoleum and plastics.
6. **Resin**. Resin is a semifluid secreted by special tubes which contains terpenes, resin acids and esters. It solidifies on exposure to air. Therefore, it plugs the places of injury. It helps in sealing female cones after pollination, scale leaves around leaf bases and apical buds. Resin retains water. It is antiseptic and toxic to pests. Therefore, it prevents microbial and insect attack. Resin is commercially extracted and distilled to obtain **turpentine** and **rosin**. Rosin is used in water proofing, sealing joints and preparation of writing paper. Turpentine is used as solvent in paints, polishes and wax. It is employed medicinally in removing pains, curing bronchitis and expelling worms.
7. **Ephedrine**. Drug ephedrine is obtained from *Ephedra*, a gymnosperm. The drug is used in curing respiratory ailments, including asthma.

ANGIOSPERMS (Gk. *angion*– vessel, *sperma*– seed)— The Flowering Plants

Angiosperms are those seed plants in which seeds are formed inside fruits and the sporophylls are organised into flowers.

1. Flowering plants or angiosperms are the most recently and highly evolved plants. They appeared on earth about 130 million years ago. First angiosperm fossil recorded from mid cretaceous period is *Archaefructus* from China and *Archaeanthus* from Canada.
2. They are the most abundant and conspicuous plants with about 270,000 (220,000 dicots and 50,000 monocots) species.

3. Flowering plants occur in most environments on the earth. Sea is the only exception. Here only two angiosperms are found. They are *Zostera* and *Thalassia*. *Wolffia* is smallest (0.1 cm) while *Eucalyptus regnans* is largest (114 m height). Angiosperms are most wide-spread in plains as well as hills. They have been recorded at an altitude of 6000 m in the Himalayas or permanently frozen Antarctica. Even deserts possess flowering plants. Some of these desert plants are able to grow soon after good shower, flower and shed seeds in a few weeks of wetness available in the area. One species is reported to occur in hot springs at 60°C. A small orchid lives underground. It has mycorrhizal association which helps it obtain nourishment from decaying organic matter. In moist areas some plants grow perched on other plants. They are dependent upon the larger plant for space only (neither food nor water). Such plants are called **epiphytes**. Epiphytes are popularly known as **space hosts**, *e.g., Vanda*.

4. Sporophylls are aggregated to form **flowers**. Therefore, angiosperms are also called flowering plants.

5. Both microsporophylls and megasporophylls are specialised. A microsporophyll or stamen consists of a filament and an anther. A megasporophyll or carpel is rolled and partly sterilised to produce a stigma, style and ovary containing ovules. Within ovules are present highly reduced female gametophytes known as **embryo sacs**. Embryo sac formation is preceded by **meiosis**. So all the cells of embryo sac are **haploid**.

6. Pollination is through several agencies but most prominent amongst them is by animals, especially insects. The flowers possess showy petals, edible pollen or nectar for this.

7. Pollen grains or microspores reach stigmatic surface found at the tip of carpel or megasporophyll.

8. Female gametophyte or **embryo sac** develops upto 8-nucleate state prior to fertilisation. There is a three cell **egg apparatus** (one egg cell or oosphere and two synergids), three **antipodal cells** and **two polar nuclei**. The two polar nuclei fuse to form a diploid **secondary nucleus**.

9. Archegonia are absent. Instead, there is one oosphere surrounded by two specialised synergid cells that attract the pollen tube. The latter brings two naked non-flagellate male gametes.

10. There is **double fertilisation**. One male gamete fuses with oosphere or egg cell to form zygote. It is called generative fertilization or syngamy. The second male gamete fuses with diploid secondary nucleus to form triploid primary endosperm nucleus (PEN). It represents vegetative fertilization. The latter is also called triple fusion since three nuclei are involved in its formation. Total 5 nuclei take part in double fertilization.

11. Zygote develops into embryo. Central cell containing triploid primary endosperm forms triploid endosperm. Endosperm provides nourishment to developing embryo. Synergids and antipodals degenerate after fertilization.

Differences between Syngamy and Triple Fusion

Syngamy	*Triple Fusion*
1. It is the actual or generative fertilization.	1. It is vegetative fertilization.
2. Both male and female gametes are involved in syngamy.	2. Only one male gamete and two vegetative nuclei are involved in triple fusion.
3. Syngamy produces a diploid zygote.	3. It produces a triploid primary endosperm cell.
4. Zygote forms the embryo.	4. Primary endosperm cell produces a food laden endosperm.

12. Fertilized ovules ripen into **seeds**. The seeds are covered by fruits. A **fruit** is technically a ripened ovary. Fruits not only protect the seeds but also help in their dispersal.

13. Xylem contains vessels.

14. Phloem possesses sieve tubes and companion cells.

15. Secondary growth occurs in stem and root of some angiosperms, placed in group dicots.

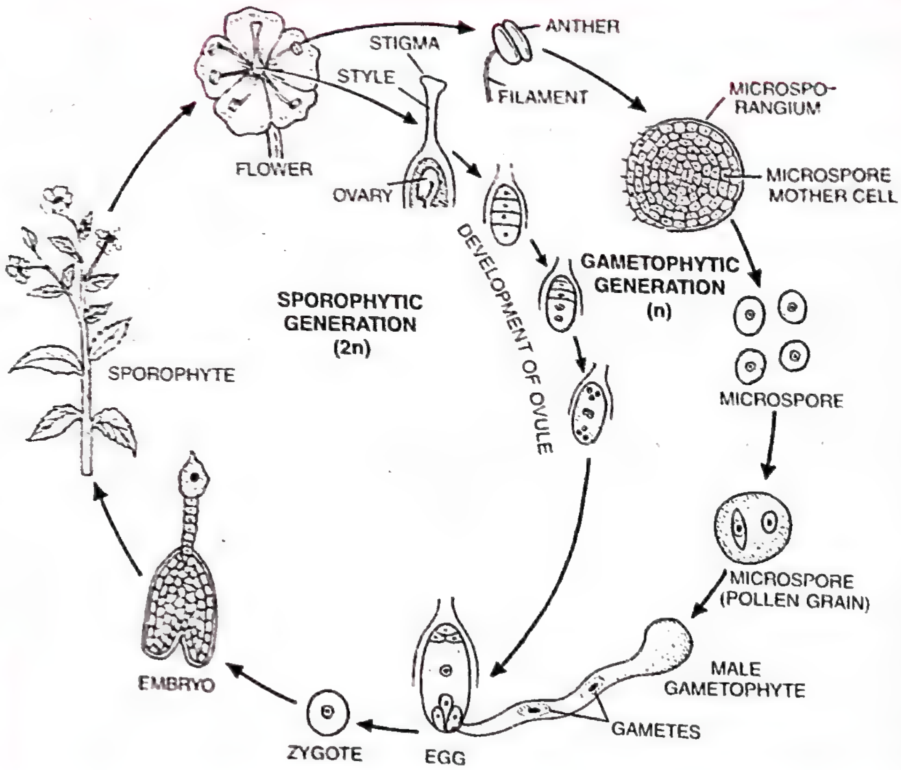


Fig. 3.20. Life cycle of an angiosperm.

Development of Flower and Fruit Habit

Flower is basically a shoot which has been modified in angiosperms for carrying out the process of sexual reproduction. A flower has a limited growth with a long internode at the base (appearing as stalk or pedicel) and condensed nodes present on thalamus or torus. The latter bears four types of structures— sepals, petals, stamens and carpels. Sepals and petals are sterile floral leaves. **Sepals** are green and cover the flower in the bud condition. They are protective in nature. **Petals** are showy and are meant for attracting animal pollinators, especially insects. **Stamens** are specialized microsporophylls. Each stamen has a narrow stalk or **filament** and a knob-like broader tip called **anther**. Anther develops four microsporangia or pollen sacs. The latter produce microspores or pollen grains. **Carpels** are specialized megasporophylls. They may be free or fused. Each carpel has a swollen base named **ovary**. The interior of ovary contains one or more placentae (singular– placenta) for bearing ovules. The tip of the carpel has sticky tip known as **stigma**. Stigma is meant for receiving pollen grains. Stigma is connected with ovary through a stalk known as **style**.

Differences between Microsporophyll and Megasporophyll

Microsporophyll	*Megasporophyll*
1. It bears microsporangia.	1. Megasporophyll bears megasporangia.
2. A microsporangium contains numerous microspores or pollen grains.	2. A megasporangium usually bears one functional megaspore.
3. Microspores or pollen grains are not retained. They are always shed.	3. In seed plants, the megaspore is retained inside the megasporangium.
4. The male gametophyte is formed near the female gametophyte.	4. In seed plants, the female gametophyte is produced inside the megasporangium. Fertilisation and embryo formation occur there.
5. In angiosperms, the microsporophyll is modified into stamen.	5. In angiosperm, the megasporophyll is rolled to produce a carpel.

Differences between Male Gametophytes of Pteridophytes and Gymnosperms

Male Gametophyte of Pteridophytes	*Male Gametophyte of Gymnosperms*
1. A distinct male gametophyte may not be present.	1. A distinct male gametophyte is always present.
2. It contains an antheridium.	2. An antheridium is not formed.
3. Male gametes are flagellate.	3. Male gametes can be flagellate or nonflagellate.
4. Male gametes reach the female gamete by swimming in a thin film of water.	4. Male gametes reach the female gamete through a pollen tube. Water is not required.

Differences between Female Gametophytes of Pteridophytes and Gymnosperms

Female Gametophyte of Pteridophytes	*Female Gametophyte of Gymnosperms*
1. A distinct female gametophyte may or may not be present.	1. A distinct gametophyte is always present.
2. It is largely independent.	2. Female gametophyte does not leave the parent plant.
3. It is not enclosed in an ovule.	3. It is enclosed inside an ovule.

The transfer of pollen grains or microspores to the receptive area of megasporophyll or stigma is called **pollination**. Cross pollination is common in which pollen grains of one flower reach the stigma of another flower. In gymnosperms, cross pollination is accomplished by wind. The same is known as **anemophily**. In angiosperms wind pollination or anemophily takes place in a few cases. In most of the plants, pollination is effected by animals— insects, worms, birds, bats and even human beings. Insects out-number all other animals as pollinators.

After falling on the stigmas, the pollen grains germinate and develop pollen tubes. The latter descend the styles, enter the ovary and then ovules to perform fertilization. After fertilization the ovules mature into **seeds**. The ovary containing the seeds ripens into a **fruit**. The name angiosperm for flowering plants is derived from their characteristics of having covered seeds or seeds enclosed inside the fruits. The fruit not only protects the seeds during their ripening but also aids in seed dispersal. Some dry fruits have explosive mechanism to throw the seeds. Other dry fruits have devices to stick to the fur of animals or float in air and water. There are other fruits in which the fruit wall is fleshy. The fleshy ripe fruits attract and tempt animals, especially birds, to eat them. However, seeds of fleshy fruits remain unharmed by their picking or even after passing through their digestive tracts. The animals disperse the seeds during the process of feeding on fruits.

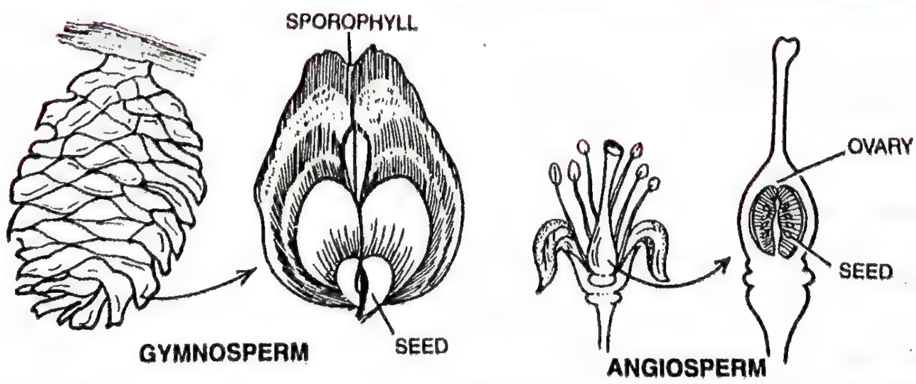


Fig. 3.21. Differences between sexual organs of gymnosperms and angiosperms.

Flowering plants have thus exploited insects, birds and several other animals as agents of pollination, fruits and seed dispersal. It is one major reason for present day dominance of flowering plants. All angiosperms, however, do not possess seeds. In some cases evolution has resulted in resorting to only vegetative means of propagation because this avoids competition from other plants. The fruits of some such plants are seedless, *e.g.*, Banana.

Differences in Reproductive Organs of Gymnosperms and Angiosperms

Gymnosperms	*Angiosperms*
1. The sporophylls are aggregated to form cones.	1. The sporophylls are aggregated to produce flowers.
2. Cones are generally unisexual, rarely bisexual.	2. Flowers are generally bisexual, rarely unisexual.
3. Cones do not possess perianth or sepals and petals.	3. The flowers usually contain perianth or sepals and petals.
4. Sporophyll bearing central axis is usually elongated.	4. Sporophyll bearing thalamus is generally short.
5. Microsporophyll often contains a broad, sterile head. Distinction into anther and filament is absent.	5. Microsporophyll is represented by a stamen. A stamen consists of a terminal broad anther and a lower stalk or filament.
6. Number of microsporangia per microsporophyll varies from 2 in *Pinus* to several hundred in *Cycas*.	6. Number of microsporangia or pollen sacs per stamen is commonly four, rarely two.
7. Megasporophyll is commonly woody.	7. Megasporophyll is delicate.
8. Megasporophyll is unrolled.	8. Megasporophyll is rolled to form a carpel.
9. Stigma and style are absent.	9. The two are present.
10. Ovules are not borne on a placenta.	10. Ovules are attached to placenta.
11. Ovules lie exposed on the megasporophyll.	11. Ovules occur covered inside the ovary part of the carpel.
12. Ovules are sessile.	12. Ovules are borne on a stalk or funiculus.
13. An ovule is covered by a 3-layered massive integument having a wide micropyle.	13. An ovule is covered by one or two thin integuments having a narrow micropyle.
14. The female gametophyte is large and parenchymatous.	14. The female gametophyte is represented by seven-celled and 8- nucleate embryo sac
15. The female gametophyte contains distinct archegonia.	15. Archegonia are absent.
16. Pollination is direct, that is, pollen grains directly enter the ovule and come to lie over the nucellus.	16. Pollination brings the pollen grains on the special receptive surface of the megasporophyll called stigma.
17. Male gametophyte contains one or two prothalial cells, a tube cell, a stalk cell and a body cell which divides to form 2 male gametes.	17. Male gametophyte consists of a tube cell and a generative cell which divides to form two male gametes.
18. Only one gamete is functional as there is only one type of fertilization or generative fertilization.	18. There is double fertilisation, that is, both the male gametes are functional, one performing generative fertilisation and other vegetative fertilisation or triple fusion.
19. Endosperm is a pre-fertilisation structure and represents the food laden female gametophyte.	19. Endosperm is a post-fertilisation structure and represents a new triploid material.
20. Seeds develop exposed on the megasporophyll. A fruit is never formed.	20. Seeds develop inside the ovary part of the carpel which matures into a fruit.
21. The embryo may contain one to several cotyledons.	21. The embryo contains one or two cotyledons.

Dicots and Monocots

Angiosperms are divided into two subgroups, **dicotyledonous** and **monocotyledonous** plants, mainly on the basis of number of embryonic leaves or cotyledons. The two are commonly spoken as dicots and monocots.

Fig. 3.22. A, Monocot Maize. B, Dicot Sunflower.

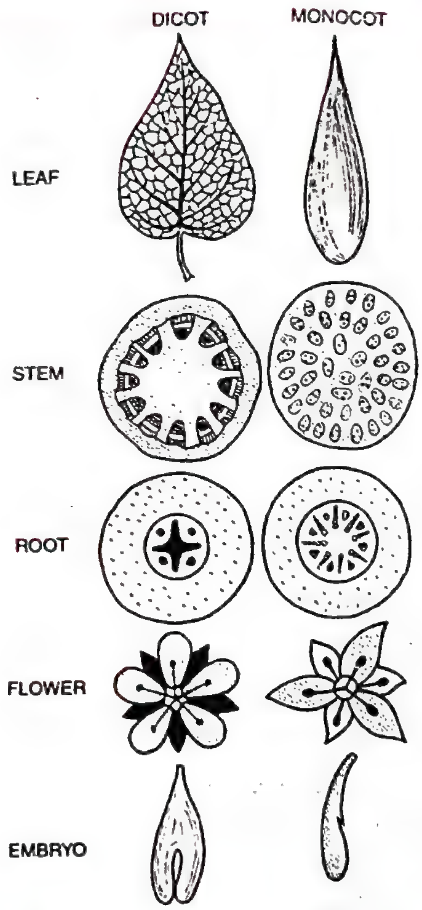


Fig. 3.23. Differences amongst different organs of dicots and

Dicots. They are angiospermic or flowering plants which are characterised by the presence of two cotyledons in the seed, generally reticulate venation in leaves (with a few exceptions), concentric tissues in the stem with open vascular bundles arranged in a ring, penta- or tetramerous flowers *e.g.*, Pea, Rose, *Eucalyptus*, Mustard, Cotton, *Acacia*, Sunflower. The number of dicot species is over 200,000.

Monocots. They are angiospermic or flowering plants which are characterised by the presence of a single cotyledon in the seed, generally parallel venation in the leaves (exception *Smilax, Colocasia* and relatives), scattered closed vascular bundles in the stem and trimerous flowers, *e.g.*, Banana, Cereals, Palms, Grasses, Bamboo, Lilies, Orchids. About 50,000 species of monocots are known.

Differences between Dicots and Monocots

Dicots	*Monocots*
1. There are usually two cotyledons.	1. The seeds contain one cotyledon.
2. Flowers are generally pentamerous or tetramerous (floral parts in sets of 5 and 4 or their multiples).	2. Flowers are usually trimerous (floral parts in sets of three or its multiples).
3. Pollen grains commonly have three germ pores.	3. Pollen grains generally possess a single germinal furrow.
4. Leaves are netveined or with reticulate venation.	4. The leaves possess parallel venation with a few exceptions.

5. Primary root often long lived forming tap root system. Adventitious roots occur in some cases.	5. Primary root is short-lived. Tap root is absent. Instead adventitious roots are found.
6. Stem possesses concentric arrangement of tissue systems— epidermis, cortex, endodermis, pericycle, pith, etc.	6. Tissue systems are not differentiated in the stem. A ground tissue occurs.
7. Vascular bundles of the stem are arranged in a ring.	7. Vascular bundles are scattered.
8. Vascular bundles of the stem possess cambium (vascular bundles open), so that secondary growth is possible.	8. A cambium is absent (vascular bundle closed).
9. In root, a pith is absent or small. The vascular bundles are few (8 or less).	9. In root, a pith is always present. Vascular bundles are many (more than 8).
10. Vessels are polygonal in outline.	10. Vessels are rounded in outline.

Alternation of Generations

Different plant groups complete their life cycles in different patterns. Angiosperms complete their life cycle in two phases— a diploid sporophyte plant body and the haploid gametophyte. The two follow each other rigidly. The phenomenon is called alternation of generations. Life cycles of other plant groups can be of following patterns.

1. **Haplontic** (Fig. 3.24). There is a single vegetative individual or somatic phase. It is haploid and is often called **gametophyte.** The haploid plant body may be unicellular, colonial or multicellular. It can *multiply vegetatively* and by *accessory spores or mitospores.* Ultimately it gives rise to haploid **gametes.** The gametes fuse and produce a diploid **zygote.** The zygote remains single-celled. It does not multiply itself, neither does it give rise to a multicellular diploid structure. Instead it may take some rest. Meiosis occurs at the time of zygote germination. Four haploid nuclei are formed as a result. Three of them degenerate in some cases a and the haploid protoplast of the zygote gives rise to new plant (*e.g., Spirogyra, Zygnema, Vaucheria,* etc.). In others the protoplast of the zygote cleaves into four meiospores (zoospores or aplanospores). The latter may divide further into 8–16 spores before liberation. An alternation of generations is absent since the plant does not have two cytologically distinct somatic phases. Some authors consider that there is an incipient alternation of generations because the zygote behaves as an incipient sporophyte by producing 4 – 16 meiospores. Examples are found in *Chlamydomonas, Volvox Spirogyra, Ulothrix, Oedogonium, Chara, Coleochaete* and several other chlorophyceae, xanthophyceae and some members of other groups.

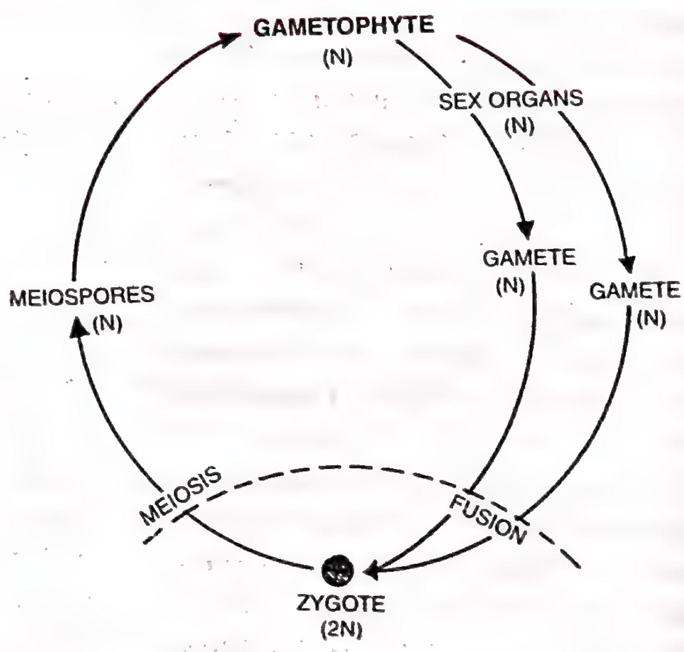


Fig. 3.24. Haplontic life history.

2. **Diplontic** (Fig. 3.25). There is a single somatic phase or vegetative individual. It is **diploid** and is often called **sporophyte** though it produces gametes in its body or sex organs. The diploid plant body is elaborated by the growth of the diploid zygote. It may multiply vegetatively and by producing accessory spores. Meiosis occurs in the plant body or its sex organs at the time of gamete formation. Therefore, the gametes are the only haploid structures in the life. They fuse during fertilisation and give rise to the diploid individual of the progeny. Alternation of generations is absent in diplontic life history. Examples occur in *Cladophora glomerata, Caulerapa, Bryopsis, Codium* and many other siphonales, some chlorococcales and fucales like *Fucus* and *Sargassum*. The diplontic life history of fucales is clearly derived from a diplo-haplontic life history where the gametophytic or haploid somatic phase gets eliminated through progressive evolution. In gymnosperms and angiosperms, sporophytic generation is dominant and independent while gametogenetic generation is highly reduced and is dependent. Therefore, many authors call their life cycle to be diplontic.

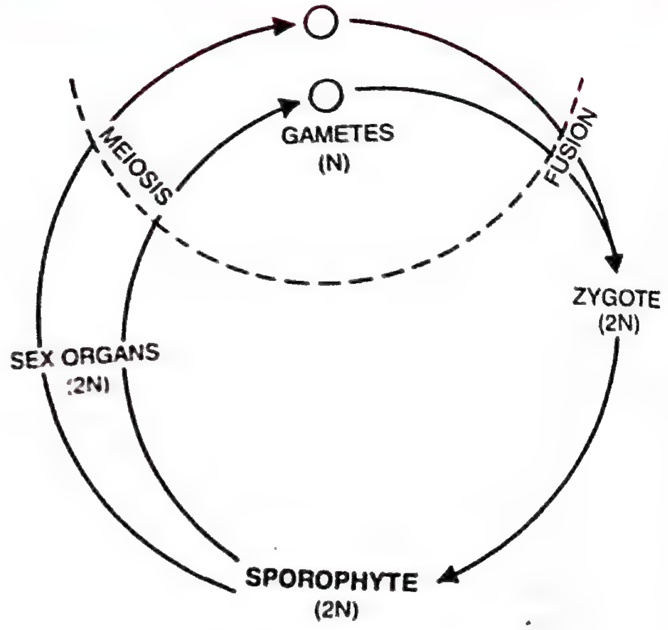


Fig. 3.25. Diplontic life history.

3. **Haplodiplontic** (Fig. 3.26). This type of life history involves the sequential recurrence of two well developed somatic phases or vegetative individuals, **gametophyte** and **sporophyte**. The sporophyte possesses diploid chromosome number (2n). Meiosis takes place in it at the time of formation of meiospores. The haploid meiospores germinate to produce haploid gametophytes. The gametophytes produce gametes. The fusion product of gametes is a diploid zygote which develops into the sporophytic thallus of the progeny. There is thus a clear alternation of generations between a haploid gamete producing gametophyte and a diploid spore producing sporophyte in diplohaplontic life history, *e.g.*, *Dictyota*, bryophytes, pteridophytes.

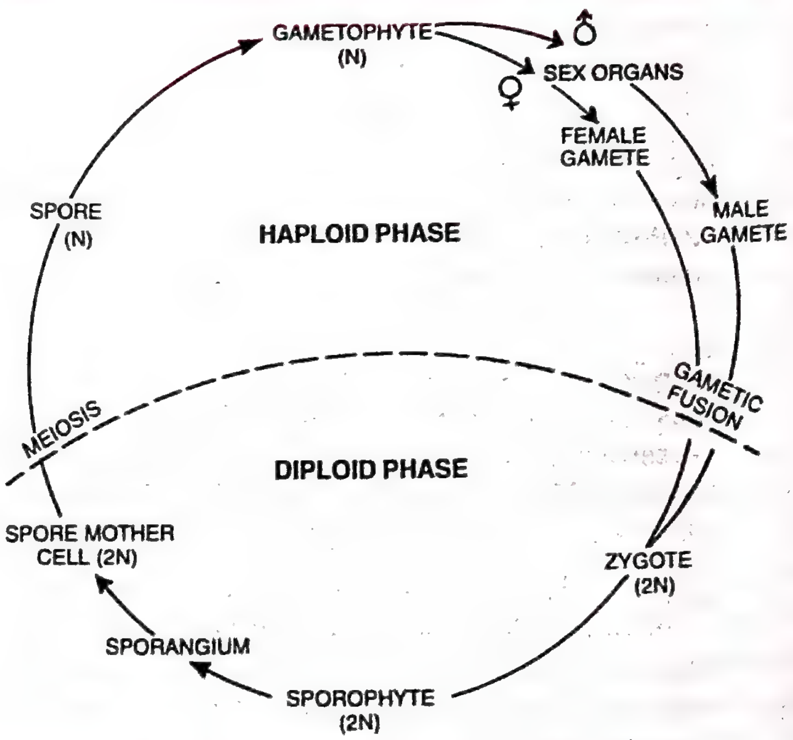


Fig. 3.26. Haplo-diplontic alternation of generations.

ADDITIONAL INFORMATION

- **Benthos.** At the bottom of water body.
- **Epilithic.** Attached to stones and rocks.
- **Epipelic.** Attached to bottom mud.
- **Pelagic.** Living in open water.
- **Apospory.** Formation of gametophyte directly from sporophyte without meiotic production of spores. Aposporously formed gametophytes are generally diploid. Apospory was discovered by Druery (1884) in fern *Athyrium*.
- **Apogamy.** Formation of sporophyte directly from gametophyte without formation and fusion of gametes. Apogamously formed sporophyte is normally haploid and nonfunctional. However, in cases where gametophytes are diploid, it survives. Apogamy was discovered by Farlow (1874) in fern *Pteris cretica*.
- *Cycas*. It has largest male cone, largest ovule, largest egg, largest sperm.
- Ephedra shows largest archegonium, largest pollen chamber and double fertilization of no importance.
- Hedwig is called father of Bryophyta.
- Theophrastus is regarded as father of Pteridophytes.
- **Tree Ferns.** Ferns with upright aerial stems, *e.g., Cyathea*.
- **Transfusion Tissue.** A tissue found in gymnosperm leaves which performs the function of lateral veins. Also called hydrostereon.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. What is the basis of classification of algae ?
   ✓ Algae are mainly classified on the basis of their pigments. Flagellation, storage products and chemistry of cell wall are also taken into account.
2. When and where does reduction division takes place in the life cycle of liverwort, a moss, a fern, a gymnosperm and an angiosperm ?
   ✓ In all these cases, meiosis is sporic and occurs at the time of asexual reproduction. It produces haploid spores. In liverworts and mosses it occurs in spore mother cells found in capsule. In ferns, it occurs in spore mother cells found in sporangia. In Gymnosperms, it occurs in microsporangium and megasporangium to produce microspores (pollen grains) and megaspore. Similarly, in angiosperms, meiosis occurs in microsporangium of anther and megasporangium of ovule.
3. Name three groups of plants that bear archegonia. Briefly describe the life cycle of any one of them.
   ✓ Archegonia are found in archegoniates like Bryophyta, Pteridophyta and Gymnosperms. You can describe the life cycle of a fern or moss.
4. Mention the ploidy of the following : protonemal cell of a moss; primary endosperm nucleus in dicot, leaf cell of a moss; prothallus cell of a fern, gemma cell in *Marchantia*; meristem cell of a monocot, ovum of a liverwort and zygote of a fern.
   ✓ Protonemal cell (haploid, x), primary endosperm nucleus of dicot (triploid, 3x), leaf cell of moss (haploid, x), prothallus cell of fern (haploid, x), gemma cell of *Marchantia* (haploid, x), meristem cell of monocot (diploid, 2x), ovum of a liverwort (haploid, x), Zygote of a fern (diploid 2x).
5. Both gymnosperms and angiosperms bear seeds, then why are they classified separately.
   ✓ Both Gymnosperms and Angiosperms belong to same group — Phanerogams/Spermatophyta as they bear visible sex organs and seeds. They are classified separately because in gymnosperms — seeds are naked, fruits absent, flowers absent, endosperm is haploid and formed before fertilization, double fertilization absent, stigma absent, archegonia present. In Angiosperms, seeds are enclosed by fruits, flowers present, endosperm is triploid and formed after double fertilization, stigma present and archegonia absent.
6. What is heterospory ? Briefly comment upon its significance. Give two examples.
   ✓ The phenomenon of having two types of spores (smaller microspores and larger megaspores) by the same plant is called heterospory. It is found in pteridophytes like *Selaginella, Salvinia, Marsilea*, all gymnosperms and angiosperms. It first appeared in pteridophytes. Heterospory is a precursor to the seed habit (tendency towards seed formation) and has led to the evolution of seed. It has helped in the differentiation of male and female gametophytes and greater chances of survival of female gametophyte that develops inside the megasporangium.

7. Explain briefly the following terms with suitable examples :
   (i) Protonema (ii) Antheridium (iii) Archegonium (iv) Syngamy (v) Sporophyll (vi) Isogamy.
   ✓ **Protonema.** It is the Juvenile, green, autotrophic filament like haploid, independent, gametophytic stage in the life cycle of mosses. It is produced from the germination of spores and gives rise to new gametophytic plants.
   Antheridium. It is multicellular, Jacketed male sex organ in bryophytes and pteridophytes. It produces sperms (antherozoids or male gametes).
   Archegonium. It is multicellular, jacketed, flask shaped female sex organ in bryophytes, pteridophytes and gymnosperms. It has a neck and swollen venter and produces a single female gamete called egg or ovum or oosphere.
   Diplontic. It is a type of life cycle in which the dominant free living phase is diploid (2x). It produces haploid gametes on gametic meiosis, *e.g., Fucus, Sargassum.*
   Sporophyll. It is a leaf that bears sporangia or sori. Sporophyll may be microsporophyll or megasporophyll. Sporophylls aggregate to form cones or strobili, *e.g.*, sporophyll of fern; micro and megasporophyll of *Selaginella, Pinus*; stamen and carpel of Angiosperms.
   Isogamy. It is a type of sexual reproduction in which the fusing gametes are similar in structure and function, *e.g., Ulothrix, Chlamydomonas, Ectocarpus.*
8. Match the plants (column I) with the plant groups (column II)

Column I Plants		Column II Groups	
(a)	*Chlamydomonas*	(i)	Moss
(b)	*Cycas*	(ii)	Pteridophyte
(c)	*Selaginella*	(iii)	Algae
(d)	*Sphagnum*	(iv)	Gymnosperm

   ✓ a— (iii), b — (iv), c — (ii), d — (i)
9. Write a note on economic importance of algae and gymnosperms.
   ✓ **Economic Importance of Algae.** Refer to the text.
   Economic Importance of Gymnosperms. Refer to the text.
10. Differentiate between (i) Red algae and brown algae. (ii) Liverworts and mosses. (iii) Homosporous and heterospoous pteridophytes. (iv) Syngamy and triple fusion.
   ✓ **(i) Differences between Red Algae and Brown Algae.** Refer to the text.
   (ii) Differences between Liverworts and Mosses. Refer to the text.
   (iii) Differences between Homosporous and Heterosporus Pteridophytes. Refer to the text.
   (iv) Differences between Synamy and Triple Fusion. Refer to the text.
11. How would you distinguish monocots and dicots ?
   ✓ Refer to the text.
12. Describe the important characteristics of gymnosperms.
   ✓ **Characters of Gymnosperms.** Refer to the text. Points 3–14.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Name an alga which is used in laboratory culture media ?
   ✓ *Gelidium*— Agar
2. Name the largest kelp ?
   ✓ *Macrocystis* (40-100m)
3. When a palmella stage is formed in algae ?
   ✓ Palmella stage is formed in response to desiccation conditions and toxic salts.
4. Define protonema stage ?
   ✓ A juvenile autotrophic filamentous stage of mosses is called **protonema**.
5. What is the importance of epizoic alga to tree dwelling sloth ?
   ✓ The alga gives protective colouration to the sloth.

6. Name the different pigments found in algae.
   ✓ Chlorophyll, carotenoids and phycobilins.
7. Name the four classes of pteridophytes.
   ✓ (i) Psilopsida (ii) Lycopsida (iii) Sphenopsida (iv) Filicopsida.
8. Fill in the blanks :
   (i) The yellow or brown spots which have sporangia in ferns are called ________.
   (ii) Cones represent the ________ organs in the gymnosperms.
   (iii) Trimerous condition of floral whorls is characteristic of ________.
   (iv) The gymnosperms are ________ seeded plants whereas the angiosperms are ________.
   (v) The ________ are root-like structures which help in anchorage and absorption of water in the bryophytes.

Three Mark Questions (Short Answer Type)

1. (a) Why are bryophytes called plant amphibians? (b) Why do we call mosses and ferns as amphibians?
2. How are vascular plants able to dominate the planet ?
3. How does an alga differ from fungi ?

Five Mark Questions (Long Answer Type)

1. Discuss the development of seed habit.
2. What characters of seed plants make them specially adapted to life on land ?
3. Describe the similarities and differences in the sexual reproduction of moss and fern.
4. Explain the terms (a) Gametophyte (b) Sporophyte (c) Alternation of Generations.

Miscellaneous Questions

1. Give the scientific names of the following :
   (a) an alga with ribbon-shaped chloroplasts (b) structure formed by the germinated fern spore.
   (c) megasporangium of seed plants.
2. Name a plant that forms fruits but no seeds, and another plant that forms seeds but no fruit.
3. Observe the relationship between the first two words and then fill in the fourth place
   (a) Angiosperms : roots :: Rhodophyta :______ (b) Fern : prothallus :: moss : ________
   (c) Moss : capsule :: fern : ______ (d) Angiosperms : flowers :: conifers ______
4. Define (a) Photic Region (b) Phycocolloids (c) Kelps (d) Moss (e) Ovule.
5. Distinguish between :
   (a) gametophyte and sporophyte (b) megasporophylls and microsporophyll
   (c) antheridia and archegonia (d) liverworts and mosses.

Multiple Choice Questions (With Answers)

(1) Chl *a*, chl *d* and phycoerythrin pigments are found in (a) Cyanophyceae (b) Bacillariophyceae (c) Rhodophyceae (d) Chlorophyceae. *(CBSE 2000)*

(2) Kelps are (a) Marine algae (b) Fresh water algae (c) Amphibious plants (d) Terrestrial plants. *(PBPMT 2000)*

(3) Non flowering plants belong to (a) Monocots (b) Dicots (c) Cryptogams (d) Phanerogams. *(BHU 2001)*

(4) *Cycas* possesses two cotyledons but is not a dicot because of (a) Compound leaves (b) Naked seeds (c) Circinate ptyxis (d) Monocot like stem. *(CBSE 2001)*

(5) A plant producing seeds but lacking flowers is (a) Gymnosperm (b) Bryophyte (c) Angiosperm (d) Pteridophyte. (CBSE 2002)

(6) A spermatophyte with ciliated stage is (a) Gymnosperm (b) *Riccia* (c) Angiosperm (d) *Pteridium*. *(BHU 2002)*

(7) Which one produces carageenin ? (a) Green algae (b) Blue green algae (c) Red algae (d) Brown algae. *(BHU 2003)*

(8) Which one is a living fossil ? (a) *Pinus* (b) *Cycas* (c) *Selaginella* (d) *Metasequoia*. *(CBSE 2003, 04)*

(9) Greatest extent of adaptation to various environments is found in (a) Gymnosperms (b) Bryophytes (c) Ferns (d) Angiosperms. *(CMC 2003)*

(10) Phycobilins occur in (a) Blue green algae (b) Red algae (c) Green algae (d) Both *a* and *b*. *(AMU 2003)*

(11) Largest unicellular organism is (a) Yeast (b) *Acetabularia* (c) *Planaria* (d) *Volvox*. *(Kerala 2004)*

(12) In *Ulothrix*, meiosis occurs in (a) hold fast (b) zygote (c) zoospores (d) cells of filament. *(AIIMS 2004)*

(13) Top-shaped multiciliate male gametes and mature seeds with one embryo having two cotyledons are characteristic features of (a) Cycas (b) Conifers (c) Gamopetalous angiosperms (d) Polypetalous angiosperms. *(CBSE 2005)*
(14) Most primitive member in which roots are not present (a) *Psilotum* (b) *Rhynia* (c) *Lycopodium* (d) *Selaginella* *(BHU 2005)*
(15) Phloem of angiosperms differs from that of other vascular plants by the presence of (a) Tylosoides (b) Vessels (c) Companion cells (d) Albuminous cells (e) Secretory cells *(Kerala 2005)*
(16) Which is resurrection plant ? (a) *Dryopteris filix-mass* (b) *Adiantum caudatum* (c) *Adiantum capillus-veneris* (d) *Selaginella lepidophylla*. *(HP PMT 2005)*
(17) *Cycas* is a gymnosperm as it has (a) Vessels (b) Nakes seeds (c) Living fossil status (d) None of these. *(Bih. PMT 2006)*
(18) *Laminaria* and *Fucus* belong to (a) Red algae (b) Green algae (c) Brown algae (d) Golden brown algae. *(AMU 2006)*
(19) Peat moss is (a) *Sphagnum* (b) *Funaria* (c) *Riccia* (d) *Marchantia* *(Orissa 2006)*
(20) A bushy trailing herbaceous gymnosperms is (a) *Cedrus* (b) *Cycas* (c) *Pinus* (d) *Ephedra* *(Kerala 2007)*
(21) Spore dissemination in some liverworts is aided by (a) Peristome (b) Elaters (c) Calyptra (d) Indusium *(CBSE 2007)*
(22) *Sphaerocarpos* belongs to (a) Bryophyta (b) Pteridophyta (c) Gymnosperms (d) Angiosperms. *(DPMT 2008)*
(23) Which one is heterosporous (a) *Dryopteris* (b) *Adiantum* (c) *Salvinia* (d) *Equisetum*. *(CBSE 2008)*
(24) Male and female gametophytes donot have free independent existence in (a) *Pteris* (b) *Cedrus* (c) *Polytrichum* (d) *Funaria*. *(CBSE 2008)*
(25) In which features does *Gnetum* differ from *Cycas* and *Pinus* showing affinities with angiosperms ? (a) Perianth and two integuments (b) Embryo development and apical meristem (c) Absence of resin ducts and leaf venation (d) Presence of vessel elements and absence of archegonia. *(CBSE 2008)*
(26) Mannitol is stored food in (a) *Chara* (b) *Porphyra* (c) *Fucus* (d) *Gracilaria*. *(CBSE 2009)*
(27) A vascular cryptogam is (a) *Equisetum* (b) *Cedrus* (c) *Marchantia* (d) *Ginkgo*. *(CBSE 2009)*
(28) Which one is peat moss ? (a) *Sphagnum* (b) *Funaria* (c) *Polytrichum* (d) *Cladonia*. *(AFMC 2010)*
(29) Male and female gametophytes are independent and free living in (a) Castor (b) *Pinus* (c) *Sphagnum* (d) Mustard. *(CBSE 2010)*
(30) Both pteridophytes and gymnosperms possess (a) ovules (b) seeds (c) archegonia (d) independent gametophyte. *(RPMT 2011)*
(31) Archegoniophore occurs in (a) *Chara* (b) *Funaria* (c) *Adiantum* (d) *Marchantia*. *(CBSE 2011)*
(32) *Cycas* and *Adiantum* resemble each other in (a) seeds (b) motile sperms (c) cambium (d) vessels. *(CBSE 2012)*
(33) How many organisms in the list given are autotrophs *Lactobacillus, Nostoc, Chara, Nitrosomonas, Nitrobacter, Streptomyces, Trypanosoma, Porphyra, Wolffia* (a) four (b) five (c) six (d) three. *(CBSE Mains 2012)*
(34) Leaves of ferns are covered with (a) Ramenta (b) Spores (c) Wax (d) Indusium. *(MP PMT 2013)*
(35) Isogamous condition with nonflagellated gametes is found in (a) *Fucus* (b) *Chlamydomonas* (c) *Spirogyra* (d) *Volvox*. *(NEET 2013)*
(36) Male gametophyte with least number of cells is present in (a) *Funaria* (b) *Lilium* (c) *Pinus* (d) *Pteris*. *(CBSE 2014)*
(37) The alga which can be employed as food for human beings is (a) *Chlorella* (b) *Spirogyra* (c) *Polysiphonia* (d) *Ulothrix*. *(CBSE 2014)*
(38) This provides brown colour to algae (a) Chlorophyll *a* (b) Phycocyanin (c) Fucoxanthin (d) Chlorophyll *b*. *(Bihar 2015)*
(39) Phanerogams without ovary are (a) Thallophytes (b) Bryophytes (c) Pteridophytes (d) Gymnosperms. *(Uttarakhand 2015)*
(40) Select the correct statement (a) Leaves of gymnosperms are not well adapted to extremes of climate (b) Gymnosperms are both homosporous and heterosporous (c) *Salvinia*, *Ginkgo* and *Pinus* are all gymnosperms (d) *Sequoia* is one of the tallest trees. *(NEET 20160*
(41) Which of the following statements is wrong (a) *Laminaria* and *Sargassum* are used as food (b) Algae increase the level of dissolved oxygen in the immediate environment (c) Algin is obtained from red algae and carrageenan from brown algae (d) Agar-agar is obtained from *Gelidium* and *Gracilaria*. *(NEET 2016)*

(42) Select one of the following pairs of important features distinguishing *Gnetum* from *Cycas* and *Pinus* and showing affinities with angiosperms (a) Perianth, no integument (b) Embryo development and apical meristem (c) Absence of resin duct and leaf venation (d) presence of vessel elements and absence of archegonia. *(AIIMS 2017)*

(43) An example of colonial alga is (a) *Chlorella* (b) *Volvox* (c) *Ulothrix* (d) *Spirogyra.* *(NEET 2017)*

(44) Select the mismatch

(a) *Pinus* — dioecious (b) *Cycas* — dioecious (c) *Salvinia* — Heterosporous (d) *Equisetum* — homosporous. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as

(a) If both A and R are true and R is the correct explanation of A.
(b) If both A and R are true and R is not correct explanation of A.
(c) If A is true but R is false.
(d) If both A and R are false.

1. **Assertion :** Red algae contribute in producing coral reefs.
   Reason : Some red algae secrete and deposit calcium carbonate over their walls. *(AIIMS 2004)*
   A B C D
2. **Assertion :** In *Spirogyra*, some cells in one of the two filaments become empty after conjugation.
   Reason : Aplanogametes from these cells pass through conjugation tube into cells of the other filament. *(EAM CET 2005)*
   A B C D
3. **Assertion :** The leaves in gymnosperms are well adapted to withstand extremes of temperature, humidity and wind.
   Reason : Like bryophytes and pteridophytes, in gymnosperms the male and female gametophytes do not have an independent free living existence.
   A B C D *(AIIMS 2014)*
4. **Assertion :** *Sphagnum* is slowly carbonised, compressed and fossilised over thousands of years to produce a dark spongy mass called peat.
   Reason : Peat helps to keep soil porous and it also improves water holding capacity of soil.
   A B C D *(AIIMS 2016)*

ANSWERS

One Mark Questions

9. (a) – (iii). (b) – (iv), (c) – (ii), (d) – (i)
10. (i) sori (ii) reproductive (iii) monocots (iv) naked, fruit bearing plants (v) rhizoids.

Miscellaneous Questions

3. (a) *Spirogyra* (b) Prothallus (c) Ovule.
4. Banana, *Pinus*
5. (a) holdfast (b) protonema (c) sporangium (d) cones.

Multiple Choice Questions

(1) —c (2) —a (3) —c (4) —b (5) —a (6) —a (7) —c (8) —b (9) —d (10) —d (11) —b (12) —b (13) —a (14) —b (15) —c (16) —d (17) —b (18) —c (19) —a (20) —d (21) —b (22) —a (23) —c (24) —b (25) —d (26) —c (27) —a (28) —a (29) —c (30) —c (31) —d (32) —b (33) —c (34) —a (35) —c (36) —b (37) —a (38) —c (39) —d (40) —d (41) —c (42) —d (43) —b (44) —a

Assertion and Reason Type Questions

(1) —A (2) —A (3) —B (4) —B

4 ANIMAL KINGDOM

USEFUL TERMS

- **Anamniotes.** Vertebrates without embryonic membranes, *e.g.*, fishes, amphibians.
- **Amniotes.** Vertebrates with embryonic membranes (chorion amnion, allantois, yolk sac), *e.g.*, reptiles, birds, mammals.
- **Acrania** or **Protochordata.** Chordates without cranium (brain box). It includes urochordata and cephalochordata.
- **Chordates.** Animals with notochord. All urochordates, cephalochordates and vertebrates are called chordates.
- **Craniata or Vertebrata.** Chordates with cranium. It includes cyclostomes, pisces, amphibians, reptiles, birds and mammals.
- **Nonchordates.** Animals without notochord (a rod like elastic structure which supports the body). Phylum Porifera to phylum Hemichordata are called nonchordates.
- **Invertebrates.** Animals without vertebral column (backbone). All the nonchordates, urochordates and cephalochordates are collectively called invertebrates.

Habitat (L. *habitare* – to inhabit). The habitat of an organism is the place where it lives. Animals have two major types of habitats, aquatic and terrestrial.

A. Aquatic Animals. They live in water. Animals of sea water are called **marine animals**. Animals of rivers, streams, lakes, ponds and even drains are called **fresh water animals**. Animals which live in between salty and fresh water are called **brackish water animals**. Brakish water has less salt content than that of ocean.

The aquatic animals are of different kinds.

1. **Zooplankton.** The aggregate of passively floating or drifting animals in a body of water is called zooplankton *e.g.*, many protozoan protists, small crustaceans (arthropods) and various invertebrate larvae.

Nanoplankton (Gk. *nanos* = 'dwarf', a prefix meaning extremely small). These plankton are too small to be caught in a plankton net.

2. **Nekton** (Gk. *nektos* = swimming). The aggregate of actively swimming aquatic organisms in a body of water able to move independently of water currents is called nekton, *e.g.*, sharks, bony fish, etc.

The animals which live in the upper layer of the sea are called **pelagic animals** which include the zooplankton and nekton.

- Coral reefs provide the best habitat for marine animals.

3. **Benthic Animals** (Gk. *benthos* = depths of sea). These animals live at the bottom of lakes, oceans and seas, *e.g.*, star fishes, sea cucumbers, sponges, corals, etc.

4. **Littoral Animals** (L. *litoris* = shore). These animals live near the sea-shore.

5. **Neritic Animals** (pertaining to shallow waters). The animals which live in the shallow waters of sea, less than 200 metres deep are called neritic animals.

6. **Lentic Animals.** These animals live in stagnant water body such as ponds, lakes, etc.

7. **Lotic Animals.** These animals live in running water such as streams, rivers, etc.

8. **Neuston** (Gk. *neustos* = swimming). A collective term used for minute organisms which rest on the surface of water.

9. **Anadromous fishes.** These marine fishes migrate from the sea into the estuaries for spawning, *e.g., Hilsa.*

10. **Catadromous fishes.** These fishes migrate from estuaries to sea for spawning, *e.g., Anguilla* (eel).

11. **Euryhaline Animals.** These animals have a wide salinity tolerance, *e.g.,* marine animals.

12. **Stenohaline Animals.** These animals have only a narrow range of salinity tolerance and hence remain resticted to either fresh water or salt water.

13. **Stenothermal Animals.** These animals can tolerate a narrow range of variation in temperature, *e.g., trouts* (a type of fishes).

14. **Eurythermal Animals.** These animals tolerate a wide range of variation in temperature, *e.g., Mahseers* (a type of fishes).

B. Terrestrial Animals. They live on land and are of different kinds.

1. **Cursorial Animals.**They run fast, *e.g.*, kangaroo, dog, horse, etc.
2. **Fossorial Animals.** They live in burrows/underground, *e.g.,* earthworm, rabbit, etc.
3. **Arboreal Animals.** They live on the trees, *e.g.,* bats, monkeys, etc.
4. **Scansorial Animals.** They climb walls, rocks, etc., *e.g.*, wall lizard, flying squirrel, etc.
5. **Volant or Aerial or Flying Animals.** They can fly, *e.g.*, winged insects, birds, bats, etc.

Habits. Habit refers to nature of the animals.

1. **Solitary Animals** live alone, *e.g.*, Tapeworm, grasshopper.
2. **Colonial Animals** live in groups and help one another and thus show social life, *e.g.*, honey bees, termites, wasps and ants.
3. **Gregarious Animals** live in groups but, do not help one another, *e.g.*, locust.
4. **Free Living Animals** lead an independent life, *e.g.*, horse, dog, etc.
5. **Parasitic Animals** depend on other animals for food, protection, etc.
6. **Sessile or Sedentary Animals** are fixed to the substratum, *e.g.*, sponges.
7. **Coprophagous Animals** eat their faecal matter, *e.g.*, rabbit.
8. **Sanguivores** feed on blood, *e.g.*, leech, bed bug.
9. **Saprophagous Animals** feed on all sorts of fluids or semifluid organic matter, *e.g.*, housefly.
10. **Cannibals** eat their fellows, *e.g.*, cockroach, bed bug.

***Esturine waters.** Waters where big rivers fall into the ocean.

11. **Planktivorous** feed on plankton, *e.g.*, young one of *Labeo* (Rohu fish), whale.
12. **Piscivorous** feed on fishes, *e.g.*, some aquatic birds.
13. **Detritivorous** feed on dead material, *e.g.*, vulture.
14. **Herbivorous** feed on plants, *e.g.*, deer.
15. **Carnivorous Animals** feed on animals, *e.g.*, lion.
16. **Omnivorous Animals** feed on all kind of food, *e.g.*, man.
17. **Larvaevorous Animals** feed on larvae, *e.g.*, *Gambusia* (mosquito fish).
18. **Grainivorous Animals** feed on grains, *e.g.*, pigeon.
19. **Folivorous Animals** eat leaves, *e.g.*, sheep, goats.
20. **Polygamous Animals** live in the company of more than one sexual partner, *e.g.*, deer, zebra, etc. (a) **Polyandrous Animals**— a female mates with more than one males. (b) **Polygynous Animals**— a male mates with more than one female.
21. **Monogamous Animals** have only one sexual parterner.
22. **Monoecious or Hermaphrodite or Bisexual Animals** are the animals in which both male and female sex organs are found in one individual, *e.g.*, Tapeworm, liver fluke, earthworm, leech, etc.
23. **Dioecious or Unisexual Animals** are the animals which have only either male or female sex organs, *e.g.*, most of animals.
24. **Protandrous Animals** are the animals in which male sex organs mature earlier than the female sex organs, *e.g.*, earthworm.
25. **Protogynous Animals** are the animals in which female sex organs mature earlier than male sex organs, *e.g.*, *Herdmania*.
26. **Oviparous Animals** lay eggs, *e.g.*, frog, birds, egg laying mammals.
27. **Ovoviviparous Animals** are the animals which give birth to young ones without placenta formation, *e.g.*, shark, viper.
28. **Viviparous Animals** give birth to the young ones with placenta formation, *e.g.*, rabbit, human beings, etc.
29. **Poikilothermal or Ectothermic or Cold Blooded Animals** are those animals in which body temperature varies according to the surrounding environment, *e.g.*, all invertebrates, fishes, amphibians and reptiles.
30. **Homoiothermal** (= **Homeothermic**) **or Endothermic or Warm Blooded Animals** are those animals in which body temperature remains constant and does not change with the change of environmental temperature, *e.g*, birds and mammals.
31. **Nocturnal Animals** like darkness, *e.g.*, Owl.
32. **Diurnal Animals** are active during day, *e.g.*, man, horse, etc.
33. **Crepuscular Animals** move about in twilight, *e.g.*, rabbit.
34. **Frugivorous Animals** feed on fruits, *e.g.*, parrot.
35. **Coprozoic Animals** feed on dung, *e.g.*, pig
36. **Vespertine Animals** are active during evening or dusk, *e.g.*, small insectivorous bats.
37. **Saltatorial Animals** are the animals whose hindlegs are long and modified for jumping, *e.g.*, locust, grasshoppers and crickets.
38. **Auroral Animals** are active during dawn.

39. **Cave Dewellers** live in caves, *e.g.,* Proteus
40. **Epilithic Animals** adhere to rocks or stones.
41. **Epiphytic Animals** get attached to the surface of plants.
42. **Epizoons** are those animals which live on the body of other animals.

Some other habits of animals are as follows.

- **Mimicry.** It is the resemblance of one organism to another or to any natural object for the purpose of concealment, protection or for some other advantage.
- **Crypsis.** It is a type of colouration in which an animal helps to camouflage in its natural environment.
- **Autotomy.** Self mutilation of a part of the body is called autotomy. It is observed in legs of prawn and in tail of wall lizard.
- **Regeneration.** Regeneration involves (1) **Epimorphallaxis** — restoration of lost part and (2) **Morphallaxis**— reconstruction of whole body from a small part of the organism's body.
- **Hibernation. "Winter sleep".** It is observed in frogs, many reptiles, and some mammals during winter season.
- **Aestivation. "Summer sleep".** It is observed in frogs during too much heat.
- **Parthenogenesis.** Development of an egg (ovum) into a complete individual without fertilization by a sperm is known as parthenogenesis. Drones (males) of honey bees are formed by parthenogenesis.
- **Paedogenesis.** When parthenogenesis occurs in larva it is called paedogenesis. It occurs in **sporocyst** and **redia** larvae of liver fluke.
- **Neoteny.** When the larva retains adult characters such as gonads and starts producing young ones by sexual reproduction it is called **neoteny.** It occurs in the **axolotl** (larva of *Ambystoma*— tiger salamander).
- **Metachrosis.** Frogs can change their skin colour according to the colour of their external environment. This capability is called **metachrosis.**
- **Pachyderms** (*i.e.,* thick skinned). Elephants are *pachyderms.*

BASIS OF CLASSIFICATION

Although there are differences in structures and forms of different animals, yet there are common fundamental features in various individuals in relation to the arrangement of cells, body symmetry, nature of coelom, patterns of digestive, excretory, circulatory or reproductive system. These features are used as the basis of animal classification.

Levels of Organisation. Four levels of organization are found in animals.

1. **Cellular Level.** The body consists of many cells which may be similar or show minor division of labour *e.g.,* sponges.
2. **Tissue Level.** The cells form poorly defined tissues, *e.g.,* Cnidarians (= Coelenterates), ctenophores.
3. **Organ Level.** Tissues are grouped together to form organs, *e.g.,* Platyhelminthes.
4. **Organ-System Level.** The cells are organised into tissues, tissues into organs and organs into organ systems, *e.g.,* Aschelminthes to chordates.

Body Plans. Animals have three types of body plans :

1. **Cell Aggregate Plan.** The body consists of a cluster or aggregation of cells. It is found in sponges.

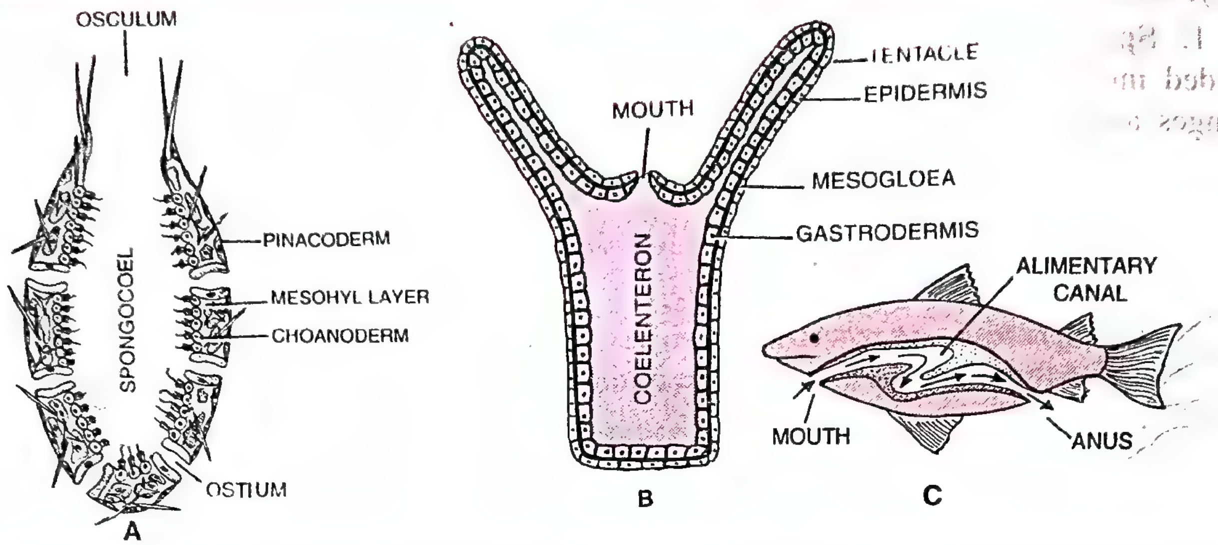


Fig. 4.1. The three basic body plans. A; Cell aggregate plan in a sponge; B, Blind-sac plan in *Hydra*; C, Tube-within-a-tube plan in fish.

2. **Blind Sac Plan.** The body has a single cavity with one opening to the outside. The single opening functions as both mouth for ingestion (intake of food) and anus for egestion (undigested food is passed out). It is found in Cnidarians (=coelenterates) and flatworms.

3. **Tube-within-a-Tube Plan.** The body has two tubes, one formed by the body wall and the second formed within it by the digestive tract. Digestive tract is a continuous tube-like structure that has two openings, a mouth for ingestion and anus for egestion. Food is digested and absorbed in the digestive tract (alimentary canal).

Protostomes And Deuterostomes

(i) **Protostomes.** The mouth of the digestive tract develops first in the embryo and anus is formed later. This occurs in flat worms, roundworms, annelids, molluscs and arthropods. The animals which have this body plan are called **protostomes** (Gr. *protos* – first, *stoma* = mouth).

(ii) **Deuterostomes**. The anus of the digestive tract develops first in the embryo and the mouth is formed later. This is seen in echinoderms, hemichordates and chordates. Thus chordates are evolutionarily closer to the echinoderms. The animals which possess this body plan are called **deuterostomes** (Gr. *deuteros* = second, *stoma* = mouth).

Differences between Protostomic and Deuterostomic Plans

Character	*Protostomic Plan*	*Deuterostomic Plan*
1. **Cleavage**	*Determinate	*Indeterminate
2. **Development of Mouth and Anus**	Mouth develops first and anus later on in the embryo.	Anus develops first and mouth later on in the embryo.
3. **Coelom**	*Schizocoelom	*Enterocoelom
4. **Examples**	Platyhelminthes, Annelida, Mollusca & Arthropoda	Echinodermata, Hemichordata & Chordata

*Explained ahead under the heading cleavage.

Symmetry. Body symmetry is the similarity of parts in different regions and directions of the body. When the body is not divisible into equal halves by any plane it is called **asymmetrical** or **asymmetric** as found in *Amoeba* and some sponges. An animal is said to be **symmetrical** if its body is divisible into equal halves by one or more planes. Three types of symmetry are usually seen in the animals.

1. **Spherical Symmetry.** In this type of symmetry, the body of the individual can be divided into similar halves by any plane passing through the centre. *e.g.*, *Volvox*, some sponges and some corals.

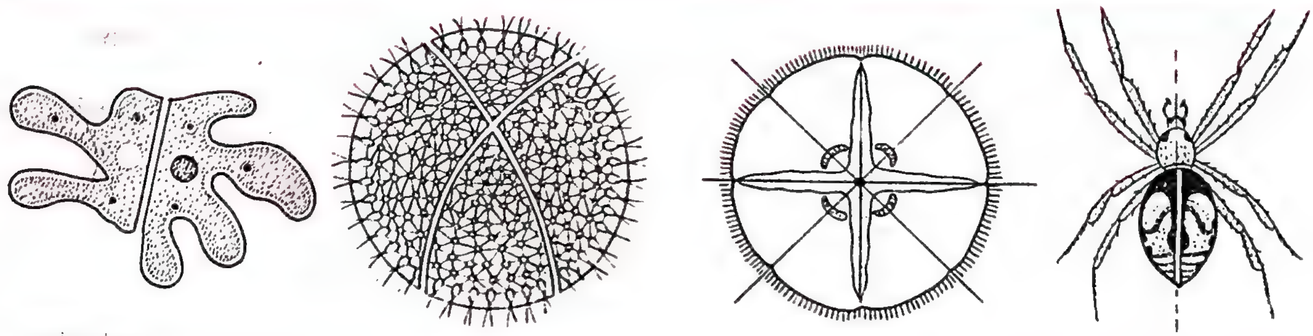


Fig. 4.2. A, Asymmetry in *Amoeba*; B, Spherical symmetry in *Volvox*; C, Radial symmetry in Jelly fish; D, Bilateral symmetry in Spider.

2. **Radial Symmetry**. In this type of symmetry, the body of the individual can be divided into equal halves by any plane passing through the centre from top to bottom. This type of symmetry is found in some sponges (*Sycon*), cnidarians (*e.g.*, *Hydra*, jelly fish), echinoderms (*e.g.*, star fish). When the body can be divided into two similar halves by one or two vertical planes only, the radial symmetry is called **biradial symmetry**. It is present in the sea anemones.

3. **Bilateral Symmetry.** In this type of symmetry, the body can be divided into two equal halves by a single plane only because the important body organs are paired and occur on the two sides of a central axis. Bilateral symmetry is found in many invertebrates and all vertebrates.

- The right and left sides of the body are called the **lateral sides**. The side of the body which is kept forward during locomotion is termed the **anterior side** and the opposite one is called **posterior side**. The back or upper surface is termed **dorsal** and the under surface (towards the substratum) is called **ventral** (*L.venter*– belly).

- The part of a tissue, organ, etc., that is nearest to the point of attachment or origin is known as **proximal end**. For example, upper arm is proximal end of the forelimb. The part of a tissue, organ, limb, etc., that is farther away from the point of attachment or origin is called **distal end.** For example, the fingers are at the distal end of the fore limb.

- **Anatomical Body Planes**. Animal body can be cut along three planes (transverse, horizontal and vertical) for examining its internal structure. A vertical section passing through the middle line of the body is known as the **saggital section**.

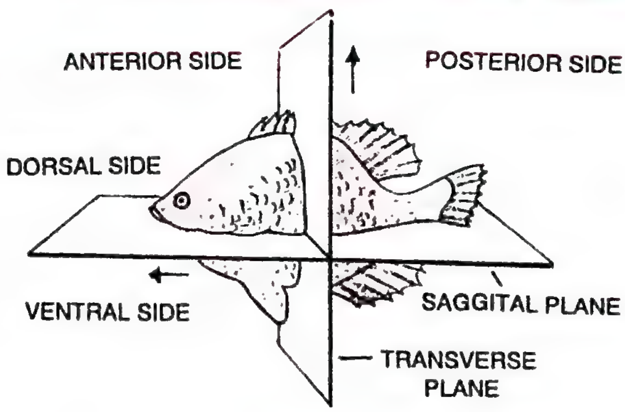


Fig. 4.3. Diagram showing the different sides, planes, etc.

Diploblastic and Triploblastic Animals. The embryos of porifers and cnidarians have two germinal layers, the **ectoderm** and **endoderm.** These animals are called **diploblastic.** An undifferentiated layer, **mesogloea,** is present in between the ectoderm and endoderm. The embryos of all other animals (from phylum Platyhelminthes to phylum Chordata) have three germinal layers— the **ectoderm, mesoderm** and **endoderm.** These animals are called **triploblastic animals.** The germinal layers form the body of the animals.

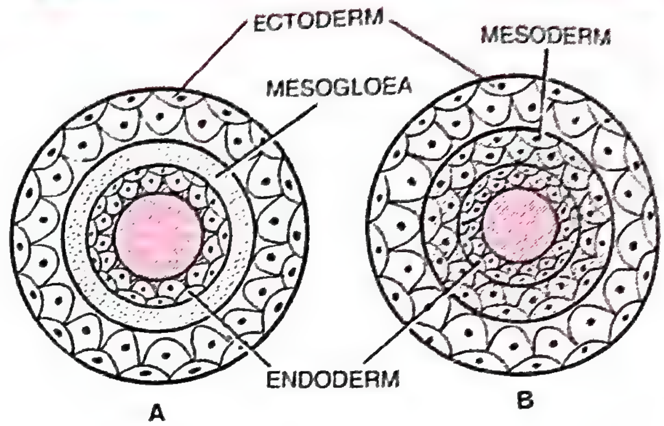


Fig. 4.4. Showing germinal layers : A, Dipioblastic ; B, Triploblastic.

Segmentation. Segmentation is division or differentiation of the body into distinct portions called segments. It is of two types: metameric segmentation and pseudo-metamerism.

(1) **Metameric Segmentation (True metamerism or True segmentation).** It is a type of segmentation where external divisions correspond to internal divisions. It occurs in three highly organized phyla — Annelida, Arthropoda and Chordata. The body is often divided both externally and internally into a number of segments (**metameres**) *e.g.*, annelids. Segmentation is mostly external in arthropods and mainly internal in man and other chordates (vertebrae, body muscles, some blood vessels and nerves).

(2) **Pseudometamerism (False segmentation).** It is found in tapeworms. The **proglottides** (segments of tapeworms) are budded off from the neck and are not of embryonic origin hence, this segmentation is called pseudometamerism (pseudosegmentation). Pseudo-segmentation as found in tapeworms is external only. The body is not internally divided.

Cephalization. Differentiation of a definite head at the anterior end is termed the cephalization. There is a concentration of sense organs, nervous tissue (brain) and food catching organs at the anterior end.

Appendages. Projecting parts from the body of an animal that serve in locomotion, feeding and other ways are called appendages. They include tentacles of cnidarians, minute **setae** and **parapodia** of many annelids, **antennae, legs** and **wings** of arthropods, **foot** of molluscs and **fins, legs** and **wings** of vertebrates.

Sexual Dimorphism. When the male and female animals can be distinguished externally, the condition is called **sexual dimorphism.** The latter is seen in male and female frogs, peacock and peahen, lion and lioness and human beings.

Fertilization. Fertilization is the union of male and female gametes. In animals, male gametes or sperms are motile. The female gametes or ova are nonmotile. When fertilization occurs outside the body of the female, it is called **external fertilization,** *e.g.*, Starfish, Frog. In many cases, fertilization takes place in the genital tract of the female. It is known as **internal fertilization,** *e.g.*, reptiles, birds, mammals.

When the fusion of male and female gametes of the same parent takes place it is called **self-fertilization,** *e.g.*, tapeworm. When the fusion of male and female gametes of different parents takes place, it is known as **cross fertilization,** *e.g.*, all fishes, amphibians, reptiles, birds and mammals.

Development. Development includes changes that an organism undergoes from its beginning to maturity. It is of two types, direct and indirect. In **direct development**, the young ones resemble the adults in all respects except colour, size. There is no intermediate stage in direct development, *e.g.*, *Hydra*, earthworm and silver fish (insect). In **indirect development**, the young ones do not resemble the adults. The young ones usually pass through one or more intermediate stages before obtaining the shape of the adults. The phenomenon of passing through different juvenile stages before attaining the form of adult is known as **metamorphosis**, *e.g.*, silk moth.

Types of Eggs. Based on the quantity of yolk, the eggs are of three types.

1. **Microlecithal Eggs.** They contain very small amount of yolk, *e.g.*, eggs of Sea urchin, Herdmania, amphioxus. The eggs of man contain very little amount of yolk, hence human egg is **alecithal** (almost free of yolk).

2. **Mesolecithal Eggs.** They contain moderate amount of yolk, *e.g.*, eggs of lamprey, lung fish, frogs and toads.

3. **Macrolecithal (Megalecithal or Polylecithal) eggs.** They contain large amount of yolk, *e.g.*, eggs of insects, sharks, bony fishes, reptiles, birds and egg laying mammals.

Based on the distribution of yolk in the cytoplasm eggs are of four types :

1. **Homolecithal Eggs.** Yolk is uniformly distributed, *e.g.*, eggs of annelids, molluscs, echinoderms and protochordates.

2. **Telolecithal Eggs.** Yolk is concentrated in the vegetal half, *e.g.*, eggs of amphibians.

3. **Meiolecithal Eggs.** Yolk is very large which occupies nearly the entire ooplasm, leaving free only a small disc like area of cytoplasm for the nucleus, *e.g.*, eggs of reptiles, birds and egg laying mammals.

4. **Centrolecithal Eggs.** Yolk is localized at the centre, *e.g.*, eggs of insects.

Cleavage. On the basis of potentiality, cleavage is of two types :

1. **Determinate (Mosaic) Cleavage.** Complete embryo is formed only if all the blastomeres remain together, *e.g.*, Annelids.

2. **Indeterminate (Non-mosaic) Cleavage.** On seperation in the early stage, blastomeres may give rise to complete embryo, *e.g.*, Chordates.

Embryo. It is an organism in early stages of development. In human beings it is from conception (act of becoming pregnant) to end of 8th week.

Foetus. Unborn young one of a viviparous animal is called foetus. In human beings an embryo is called foetus from end of 8th week till birth.

Acoelomates. The animals which do not have coelom are called **acoelomates** *e.g.*, sponges, cnidarians, ctenophores and flat worms.

Pseudocoelomates. The mesoderm is present as scattered pouches in between the ectoderm and endoderm. Such a body cavity is called **pseudocoelom** and animals possessing them are called pseudocoelomates. Round worms are **pseudocoelomates.**

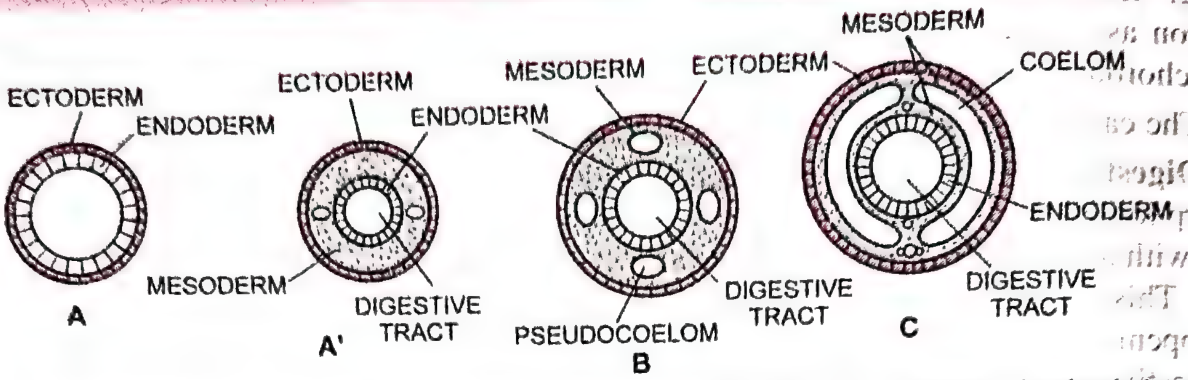


Fig. 4.5. Body cavity or coelom. Cross-sectional diagrams of the three main types of animals based on the absence or presence and type of body cavity or coelom. A and A′, Acoelomates; A— without mesoderm (sponge and coelenterate) A′; —with mesoderm (flatworm); B, Pseudocoelomate (roundworm); C, Coelomate (all other phyla).

Eucoelomates (Coelomates). The animals which possess true coelom are called eucoelomates or coelomates. *The true* ***coelom*** *is a body cavity which arises as a cavity in embryonic mesoderm.* In this case, the mesoderm of the embryo provides a cellular lining, called **coelomic epithelium** or **peritoneum**, to the cavity. The coelom is filled with **coelomic fluid** secreted by the peritoneum. True coelum is found in annelids, echinoderms and chordates. True coelom is of two types; schizocoelom (schizocoel) and enterocoelom (enterocoel).

1. **Schizocoelom.** It develops as a split in the mesoderm sheet. It is found in annelids, arthropods, molluscs.

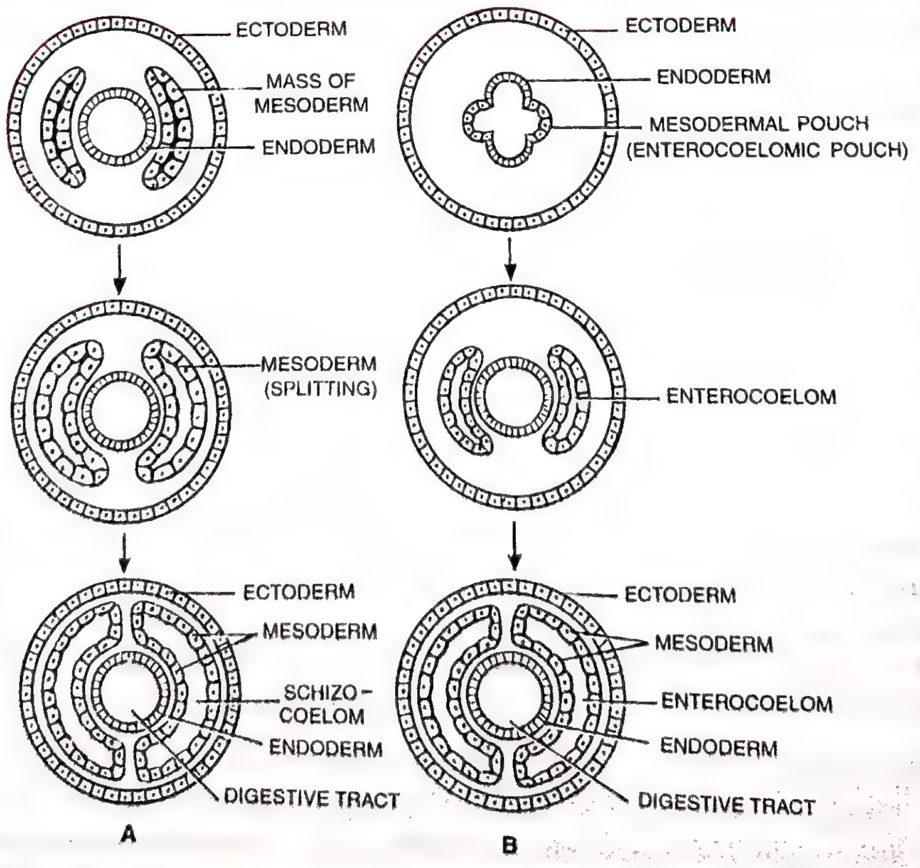


Fig. 4.6. A, Schizocoelom development (in the earthworm); B, Enterocoelom development (in a vertebrate).

2. **Enterocoelom.** The mesoderm arises from the wall of the embryonic gut or enteron as hollow outgrowths which form this type of coelom. It occurs in echinoderms and chordates.

The cavity filled with blood is called **haemocoel.** It is found in arthropods and molluscs.

Digestive Tract. Digestive tract is the passage where food is taken for digestion, absorption and elimination of undigested food. Cnidarians and flat-worms have a digestive tract with a single opening termed **mouth** that takes food as well as eliminates the undigested food. This type of digestive tract is called **incomplete**. Digestive tract of many animals has two openings; mouth for intake of food and anus for the elimination of faecal matter. Such a digestive tract is termed **complete**. It is found from round worms to mammals.

Digestion. Digestion is the breaking down of complex organic food molecules (carbohydrates, fats, proteins and nucleic acids) into simpler organic molecules by hydrolysis. Digestion is of two types; **intracellular** digestion and **extracellular** digestion.

- Cnidarians, flat worms and protochordates carry on both intracellular and extracellular digestion.

Heterotrophic Mode of Nutrition. Heterotroph is an organism that cannot use inorganic materials to synthesize the organic compounds needed for growth but obtains them by feeding on other organisms or their products. **Examples :** Carnivore, herbivore, omnivore, parasite, scavenger or saprophyte (All animals, fungi and most bacteria are heterotrophs). The nutrition is called **heterotrophic nutrition**.

Active Movement. As compared to members of other kingdoms, animals perform more rapid and complex way of movement. Movement of animals is due to the flexibility of their cells, which is perhaps the most characteristic feature of the animals. Some animals can swim (*e.g.,* jelly fish, squids, fishes, whales, etc), some can fly (*e.g.,* butterflies, birds, bats) and others can run or walk on land (*e.g.,* horses, cattle, tigers, lions, men, etc.)

Blood Vascular System. It is a system that takes part in continuous flow of blood in the body. Blood is not present in porifera, cnidaria, ctenophora, platyhelminthes and aschelminthes (nemathelminthes). Blood vascular system is of two types, closed and open. (i) In **closed type**, the blood circulates inside the blood vessels without ever coming in direct contact with the body cells, *e.g.,* annelids, chordates. (ii) In **open type** the blood flows in open spaces like **lacunae** and **sinuses**. It bathes the cells directly, *e.g.,* arthropods, molluscs. Blood may be colourless (*e.g.,* insects), bluish due to a respiratory pigment, the **haemocyanin** (*e.g.,* prawn, pila) or red due to respiratory pigment, the **haemoglobin** (*e.g.,* earthworm, vertebrates).

Respiration (Exchange of Gases). Aerobic animals utilize oxygen which is obtained from air or water. Certain aquatic animals like *Hydra* take oxygen and give up carbon dioxide through body surface. This is termed **body-surface respiration**. Many animals such as prawn, unio, fish have **gills** for exchange of gases. This type of respiration is called **branchial respiration**. In earthworm, leech, frog, etc., exchange of gases takes place through skin, this is termed as **cutaneous respiration**. In insects and other arthropods, there are present tubular structures, the **tracheae** for exchange of gases, this is called **tracheal respiration**. In arachnids (*e.g.,* spiders) exchange of gases takes place through book-like structures, the **book-lungs. Book gills** are respiratory organs in king crabs.

Lungs are meant for exchange of gases in many animals (*e.g.,* amphibians, reptiles, birds, mammals). This type of respiration is termed **pulmonary respiration.** In certain animals like frogs and toads exchange of gases also takes place through the epithelial lining of the buccopharyngeal cavity. This is called **buccopharyngeal respiration.** The frogs have

three modes of respiration namely cutaneous, buccopharyngeal and pulmonary. Lung fishes respire through both gills and lungs.

Anaerobic respiration (in absence of oxygen) occurs in various parasitic animals.

Excretion. Excretion is the removal of the metabolic wastes from the body. Sponges, cnidarians, ctenophores and echinoderms lose metabolic wastes by diffusion through body surface. Many animals have definite excretory structures. The flat worms have **flame cells** as excretory structures. In *Ascaris* (round worm), 'H' shaped excretory system of canals and complicated "giant cell" called **renette cell** is present. Annelids have **nephridia** as excretory organs and crustaceans such as prawn contain **antennary (green) glands** in the antennae as excretory organs. Insects and some other arthropods have **Malpighian tubules** as excretory organs. Molluscs and vertebrates have **kidneys** as excretory organs. Excretory organs not only remove metabolic wastes but also maintain water and salt content in the body (**osmoregulation**).

Animals are also classified on the basis of the removal of nitrogenous wastes.

1. **Ammonotelic Animals.** They excrete ammonia. Examples: protozoans (*e.g., Amoeba, Paramecium*), sponges (*e.g., Sycon*), cnidarians or coelenterates (*e.g., Hydra*), Liver fluke, Tape worm, *Ascaris, Nereis,* Earthworm, Leech, Prawn, *Pila,* Bony fish (*e.g., Labeo*), Amphibian tadpoles, tailed amphibians (*e.g.,* Salamanders), Crocodiles.

2. **Ureotelic Animals**. They excrete urea. *Examples:* Cartilaginous fishes (*e.g.,* Sharks and Rays), semi-aquatic amphibians (*e.g.,* frogs and toads), turtles, alligators, mammals including man. *Ascaris* and Earthworm are both ammonotelic and ureotelic.

3. **Uricotelic Animals**. They excrete uric acid. Examples: Most insects, some land crustaceans (*e.g., Oniscus*– commonly known as wood louse), land snails (*e.g., Helix*— commonly called "land snail"), land reptiles (lizards and snakes), birds.

4. **Aminotelic Animals**. They excrete excess amino acids. Examples: Some molluscs (*e.g., Limnaea, Unio*), some echinoderms (*e.g., Asterias*— star fish).

5. **Guanotelic Animals**. They excrete guanine. Example : *Spider*.

Dual Excretion. Some animals perform two modes of excretion. That is called **dual excretion. Earthworms** excrete ammonia when sufficient water is available while they excrete urea instead of ammonia in drier surroundings. When **lung fishes** and *Xenopus* (**African toad**) live in water they are normally ammonotelic but they become ureotelic when they lie immobile in moist air or mud during their metamorphosis. **Crocodiles** spend most of their time in water and are normally ammonotelic but when kept out of water the excretion of urea and uric acid increases. **Frog's tadpoles** excrete ammonia in water but semi-aquatic frogs excrete urea.

Neural System. Neural system is a system of **neurons** (nerve cells) that take part in conduction of impulses and coordination of body activities. Sponges do not possess nerve cells. Cnidarians have network of nerve cells that form "primitive type" of neural system. In flat worms and round worms the neural system consists of nerve ring around the anterior part of the alimentary canal and many nerve cords. In annelids and arthropods it comprises a nerve ring around the anterior part of the alimentary canal and a double ventral solid nerve cord containing **ganglia.** In molluscs, the neural system consists of ganglia, commissures and connectives. A commissure joins two similar ganglia. A connective connects two different ganglia. In echinoderms there are usually present oral and aboral nerve rings and radial nerves. Chordates have dorsally placed hollow nerve cord. In vertebrates the neural system consists of three parts; central neural system, peripheral neural system and autonomic neural

system. The **central neural system** comprises the **brain** and **spinal cord**. The brain is situated in the **cranium** (brain box) of the skull and the spinal cord lies in the **neural canal** of the vertebral column (back bone). The nerves which arise from the central neural system constitute the **peripheral neural system**. The latter includes the **cranial nerves** arising from the brain and the **spinal nerves** originating from the spinal cord. The **autonomic neural system** comprises the **sympathetic** and **parasympathetic neural systems**.

Receptors. A receptor is a sensory cell or organ which receives **stimuli** (changes in the environment) from outside or inside the animal and passes impulses to the neural system. The receptors are always connected with the central neural system by means of sensory nerve fibres. Different types of receptors such as eyes, ear, skin etc. are found in various animals.

Endocrine glands. These glands are also called **ductless glands**. Their secretions are known as **hormones**. The latter are mostly transported by blood from the endocrine glands to the **target** cells or **organs** for their physiological activity.

Skeleton. Hard external or internal structures of animal body constitute the **skeleton**. Skeleton supports and protects soft parts of the body. It is of two types; **exoskeleton** and **endoskeleton**. Exoskeleton lies outside the body of an animal and is made up of nonliving materials. Examples of exoskeleton are **chitinous cuticle** of arthropods, **calcareous shell** of molluscs, and **scales, feathers, hair, horns, hoofs, claws, nails** and **hair** of vertebrates. Endoskeleton lies entirely within the body of the animal. In vertebrates, it is composed of living hard connective tissues, namely **cartilages** and **bones**. In invertebrates such as sponges it is made up of calcareous and siliceous **spicules**. In some echinoderms (*e.g.,* star fish) calcareous plates, the **ossicles**, which form the endoskeleton, are found in the dermis of the body wall.

Notochord. It is a solid flexible rod like structure found in all chordates. It is derived from the mesoderm.

Differences between Exoskeleton and Endoskeleton

Exoskeleton	*Endoskeleton*
1. It is present outside the body.	1. It is present inside the body.
2. It is formed from ectoderm or mesoderm.	2. It is formed from mesoderm or endoderm.
3. **Examples** : Shell of molluscs and scales, feathers, hair, etc. of vertebrates.	3. **Examples** : Cartilages and Bones of vertebrates and spicules of sponges.

Classification of Animals

Aristotle (384–322 B.C.) divided animals into two main groups :

1. **Anaima.** This group includes animals without red blood, *e.g.,* sponges, cnidaria, mollusca, arthropoda, echinodermata, etc.

2. **Enaima.** This group includes animals with red blood, *e.g.,* vertebrates.

Whittaker's Five Kingdom Classification

R.H. Whittaker (1969), an American taxonomist, divided all the organisms into five kingdoms. As the viruses are on the border line of living and nonliving, they have been left out. Whittaker's five kingdom includes Monera, Protista, Plantae, Fungi and Animalia.

Outline Classification of Kingdom Animalia

A broad classification of animalia based on common fundamental features is given below.

Kingdom — *Level of Organisation* — *Symmetry* — *Body Cavity or Coelom* — *Phylum*

- Animalia (multicellular)
  - Cellular Level — Porifera
  - Tissue/Organ/— Organ system
    - Radial — Cnidaria (Coelenterata), Ctenophora
    - Bilateral
      - Without coelom (Acoelomates) — Platyhelminthes
      - With False Coelom (Pseudocoelomates) — Aschelminthes (Nemathelminthes)
      - With true coelom (Coelomates) — Annelida, Arthropoda, Mollusca, Echinodermata, Hemichordata, Chordata

ADDITIONAL INFORMATION

- Largest phylum of animal kingdom is Arthropoda.
- Largest class is Insecta.
- Phylum Ctenophora and Phylum Echinodermata are exclusively marine animals.
- **Karyotaxonomy** is based on number of chromosomes.
-

Names of Books	*Authors*
Historia Animalium	Aristotle
Systema Naturae	Linnaeus
Historia Naturalis	Pliny
Historia Naturelle	Georges Buffon

- **Biological species concept** was introduced by **Ernst Mayr** (1942).
- The term '**New systematics**' was proposed by **Sir Julian Huxley** (1940).
- Takhtajan says "Taxonomy without phylogeny is similar to bone without flesh". Phylogenetic classification is based on common evolutionary descent. Modern method of classification is called **cladistics** and is based on evolutionary history.
- **Lotsy** (1918) gave **genetic species concept**.
- **Cleidoic egg.** Egg of terrestrial animal (*e.g.*, bird and insect) enclosed within protective shell, permitting gaseous exchange.

Phylum Porifera—The Sponges (Pore Bearing Animals)

(Gk. *Porus*– Pore; *ferre*– To bear)

John Ellis (1765) first recognised sponges as animals. **Robert Grant** (1825) finally proved animal nature of sponges and gave the name "**Porifera**". About 5000 species of sponges are known.

General Characters

1. **Habitat.** All sponges are aquatic, mostly marine, rarely fresh water (*e.g.*, *Spongilla*), solitary or colonial, sessile (attached to the substratum). Sponges like warmer water. They are not usually found in cold water.

2. **Body Form.** Their body is porous, *viz.*, provided with pores. The pores are of two types: inhalent pores are called **ostia** (sing. **ostium**) and exhalent pores are known as **oscula** (sing. **osculum**; Fig. 4.7).

3. **Symmetry.** Most of the sponges are asymmetrical. Some are radially symmetrical.

4. **Germ Layers.** The sponges are the first multicellular **diploblastic animals**, *i.e.*, derived only from two embryonic germ layers, *viz.*, **ectoderm** and **endoderm**.

5. **Level of Organization.** The sponges have **cellular level of organization.**

6. **Body wall.** The body wall of a common sponge consists of three layers.

(a) **Pinacoderm (= dermal layer).** It is outer cellular layer which consists of (i) flattened **pinacocytes** and (ii) oval **porocytes** (Fig. 4.7 & 4.8).

(b) **Choanoderm (= gastral layer).** It is inner cellular layer which consists of highly specialized flagellated cells called **choanocytes** or **collar cells** (Fig. 4.7 & 4.8).

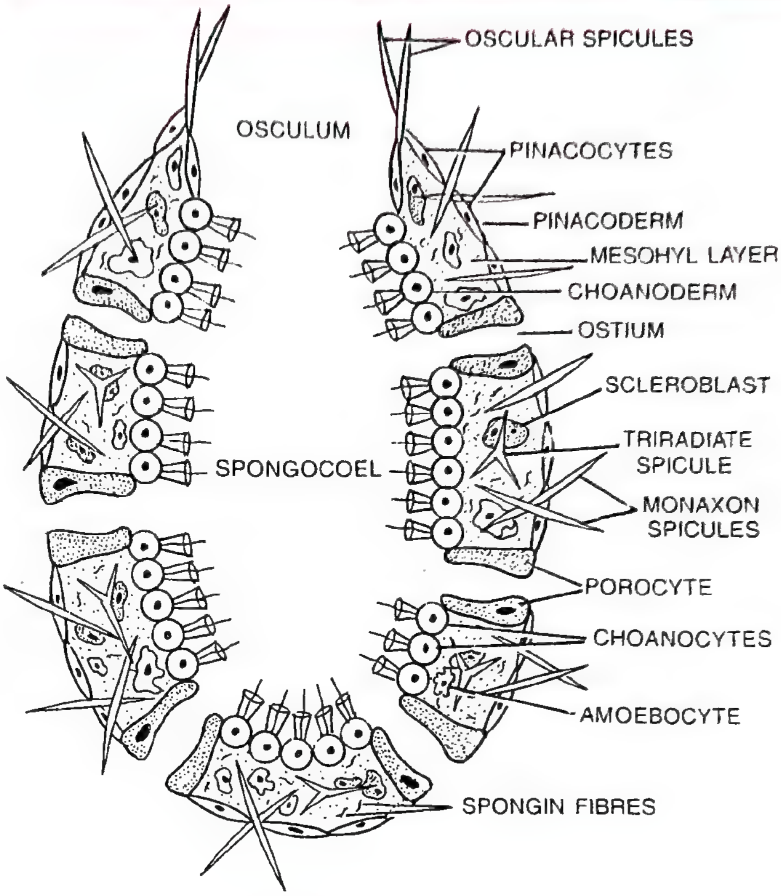


Fig. 4.7. Longitudinal section of a simple sponge.

Both pinacoderm and choanoderm do not have basement membrane.

(c) **Mesohyl layer (= mesenchyme).** Basically, it is a noncellular layer found in between pinacoderm and choanoderm. It has fine dispersed spongin fibres and numerous spicules (Fig. 4.7). It also contains **amoebocytes** (amoeba-like cells) of both pinacoderm and choanoderm. Amoebocytes are modified into following cells (Fig. 4.8). (i) **Archaeocytes** may be converted into other types of cells and are also called undifferentiated **"totipotent" cells**. (ii) **Trophocytes** provide food to developing cells and are called **nurse cells**. (iii) **Thesocytes** store food granules. (iv) **Gland cells** secrete a slimy substance. (v) **Collencytes** secrete spongin fibres of the mesohyl layer. (vi) **Scleroblasts** secrete spicules. In calcareous sponges, they are called **calcoblasts**. (vii) **Myocytes** form a circular ring around the osculum and help in closing and opening of the osculum. (viii) **Germ cells (Sex cells)** form sperms and ova and develop during breeding season. (ix) **Chromocytes** contain pigment granules and excretory substance. (x) **Phagocytes** collect food from choanocytes through their pseudopodia and also engulf excreta and damaged tissues.

7. **Canal System.** This system consists of pores and canals. Three types of canal systems are found in sponges: (i) **Asconoid canal system.** It is the simplest type which is found in *Leucosolenia* and a few other sponges, (ii) **Syconoid canal system.** It is more complex than the ascon type. It is found in *Sycon* and some other sponges. (iii) **Leuconoid canal system.** It is most complex canal system which is found in *Spongilla* and some other sponges. In class Demospongiae the leuconoid condition is derived from a larval stage,

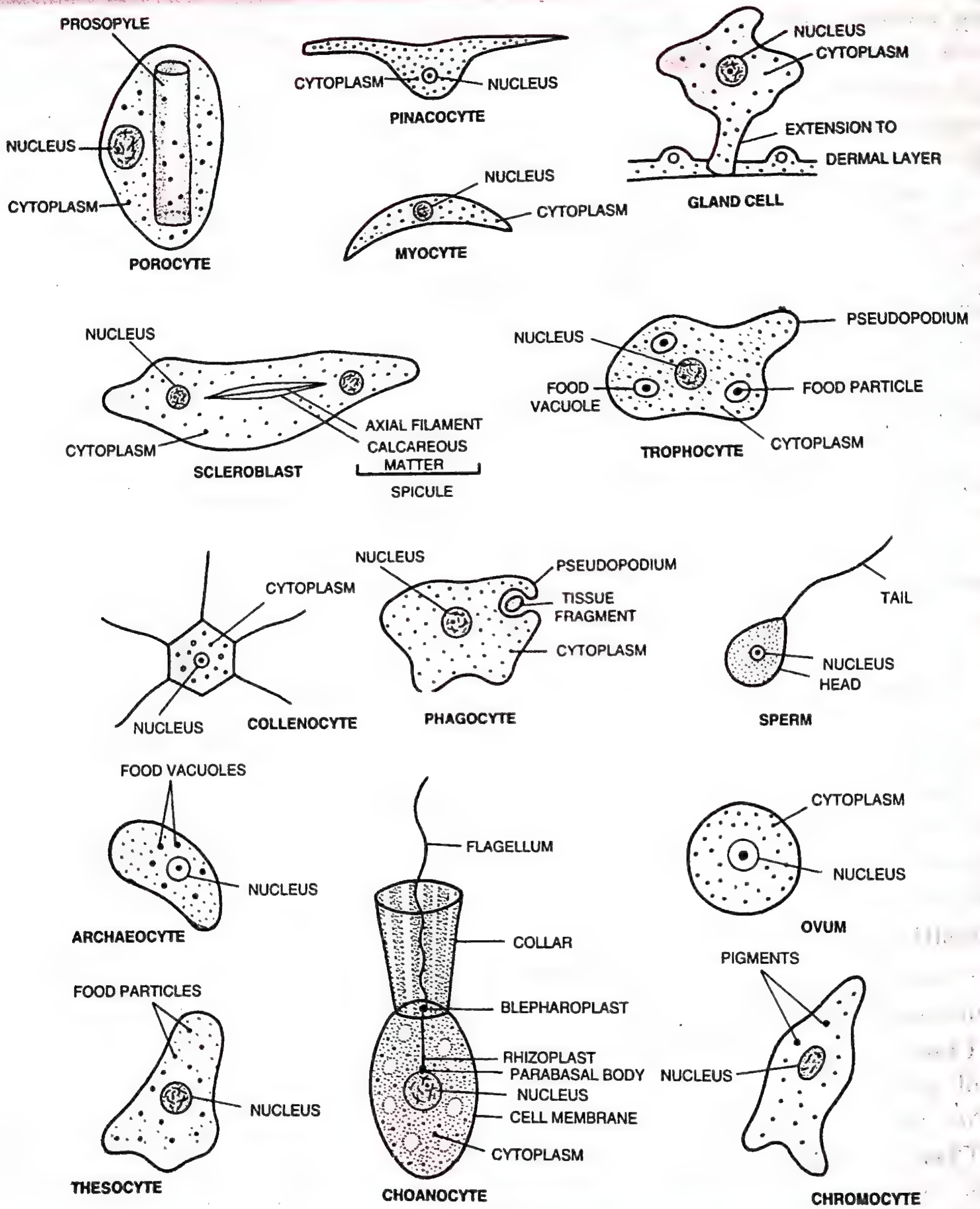


Fig. 4.8. Types of sponge cells.

called the **rhagon**. The canal system of rhagon larva does not occur in any adult sponge. Because of its derivation from rhagon stage in Demospongiae, the leucon type of canal system is also called the **rhagon type**.

The central body cavity of a sponge is called **spongocoel** or **paragastric cavity**.

The continuous water current flowing through the canal system is very important for the life of a sponge. It brings in food and oxygen and carries away carbon dioxide, excretory matter and reproductive bodies. Thus the canal system helps the sponge in nutrition, respiration, excretion and reproduction.

8. **Skeleton** (Fig. 4.7& 4.9). Almost all sponges possess an internal skeleton. It may consist of calcareous or siliceous **spicules** or of fine **spongin fibres** or of both, located in the mesohyl layer.

9. **Digestion**. It is **intracellular** and takes place inside food vacuoles as in protozoans.

10. **Circulation**. Distribution of food from the ingesting cells to others is brought about by wandering amoebocytes of mesohyl layer.

11. **Respiration**. Exchange of gases occurs by diffusion through the plasma membranes of the cells as in protozoans.

12. **Excretion**. Removal of excretory matter also occurs by diffusion through the plasma membranes of the cells as in protozoans. Ammonia is chief excretory waste.

13. **Reproduction**. Both asexual and sexual reproduction occur in sponges. Asexual reproduction occurs by **budding** and **gemmules**.

In fresh water and a few marine sponges, **gemmules** or internal buds (Fig. 4.10) are formed. Sponges are **hermaphrodite**. Fertilization is internal.

14. **Development**. Zygote undergoes **holoblastic cleavage** (complete division of the zygote). The development includes a free swimming larva, the **amphiblastula** (in *Sycon*) or **parenchymula** (in *Leucosolenia*) for dispersal of the species.

Unique features. (i) Ostia and oscula present. (ii) Presence of canal system and (iii) Skeleton made up of spicules and spongin fibres. (iv) Choanocytes.

Advancement over Protozoa. (i) Multicellular body. (ii) Division of labour among the cells. (iii) Male and female gametes are sperms and ova. (iv) Unicellular zygote undergoes cell division (mitosis) to form embryo.

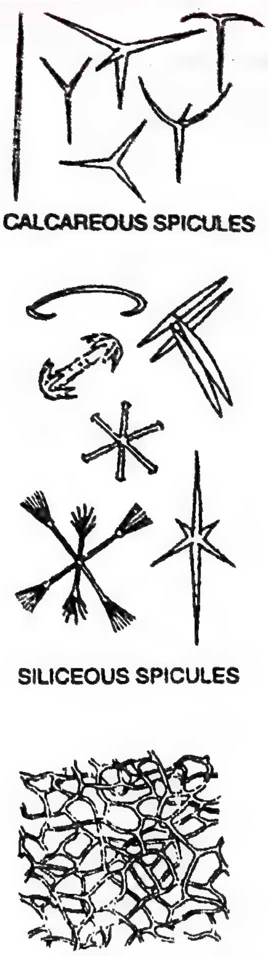


Fig. 4.9 Spicules and spongin fibres.

Classification

Chiefly *on the basis of skeleton*, phylum Porifera is divided into three classes.

Class 1. Calcarea (L. *Calcis*– lime). The skeleton is of calcareous spicules. **Examples:** *Leucosolenia, Sycon, (Scypha) Grantia.*

Class 2. Hexactinellida (Gk. *hexa– six*). The skeleton is of siliceous spicules which have six rays. **Examples :** *Euplectella, Hyalonema*

Class 3. Demospongiae. (Gr. *demas*– frame). The skeleton is of spongin fibres or of spongin fibres with siliceous spicules or may be absent. **Examples :** *Euspongia, Spongilla, Cliona, Chalina.*

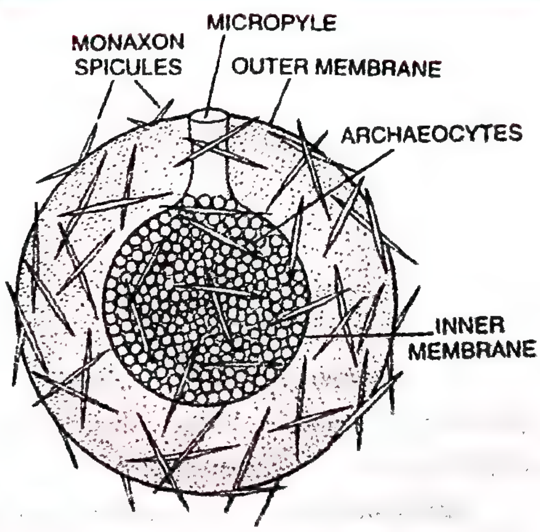


Fig. 4.10. A gemmule.

Leucosolenia. It is a simplest colonial sponge consisting of number of horizontal and vertical tubes. The development is with a larva, the parenchymula.

***Sycon* (= Scypha).** The development is with a larva, the amphiblastula.

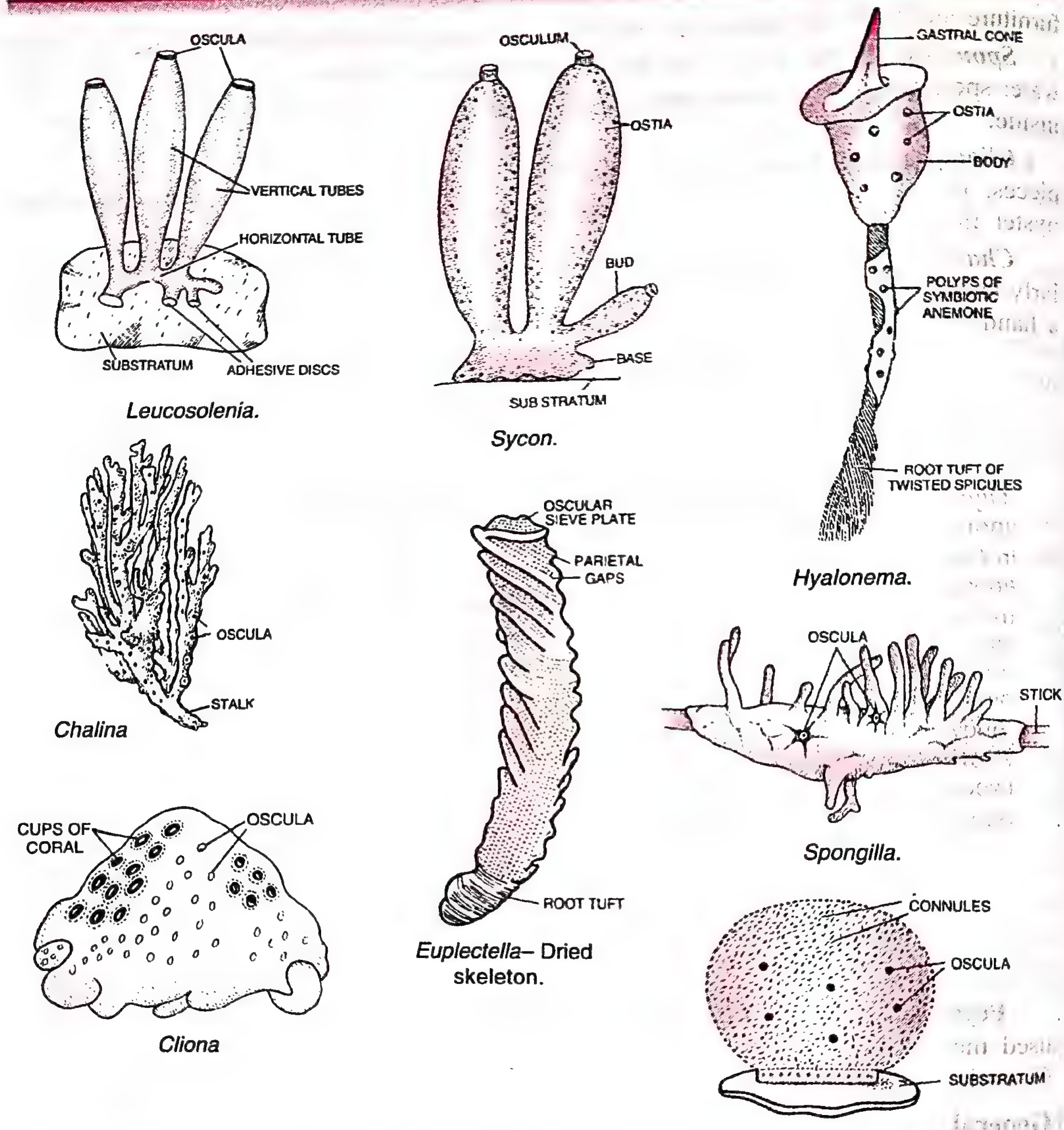


Fig. 4.11. Some Sponges.

Euplectella **(The Venus' flower basket).** It is found in deep sea water. They are abundant near the Phillipine Island and West Indies. *Its skeleton is costly marriage gift in Japan* as it is thought to be a symbol of union of wife and husband.

***Hyalonema*— The glass rope sponge.** Hyalonema is fixed in the mud by a root tuft of long, twisted spicules. The upper surface has the **gastral cone** which bears opening of the excurrent canals. The middle part of the root tuft commonly bears several polyps of symbiotic anemones of the genus *Epizoanthus* or *Polythoa* which show symbiotic relationship.

Euspongia (*Spongia*)— The bath sponge. The surface is raised into small projections, called the **connules**. Depressions between the connules bear small pores, the **dermal ostea**.

The **oscula** are numerous. Its skeleton is used for bathing, washing automobiles, cleaning furniture and window panes. It is used for applying cosmetics, mopping, etc.

Spongilla **(Fresh water sponge).** Spongilla is a common, widely distributed fresh water sponge shows various shades of green colour because of the symbiotic algae present inside.

Cliona **(The Boring Sponge).** The sponge can penetrate the rocks and break them into pieces. The sponge can also bore through the oyster shell and, therefore, harmful for pearl oyster industry.

Chalina **(The Deadman's Fingers** or **"The Mermaid's gloves").** The sponge is popularly known as "the deadman's fingers" or "the mermaid's gloves", because it is shaped like a hand with several fingers perforated with oscula.

ADDITIONAL INFORMATION

- '*Olynthus*'- Hypothetical ancestor of sponges.
- In *Leucosolenia* spongocoel is lined by choanocytes.
- In Sycon, incurrent canals are lined by pinacocytes. Radial canals are lined by choanocytes. Spongocoel is also lined by pinacocytes.
- Study of sponges is known as **parazoology**.
- ***Proterospongia*** is a connecting line between protozoa and porifera.
- Sponges have great power of regeneration.
- Sensory and nerve cells are absent in sponges.
- **Smallest sponge**— *Leucosolenia blancha.*
- **Largest sponge**— *Spheciospongia vesparium*
- **Tallest sponge**— *Poterion*
- Asconoid canal system (e.g., *Leucosolenia*).
- Syconoid canal system (*e.g., Sycon*).
- Leuconoid canal system (*e.g., Spongilla*).
- Rhagon canal system, (*e.g.,* Rhagon larva).
- W. V. Wilson studied regeneration first time in sponges.

Phylum Cnidaria (= Coelenterata)

(Gk. *knide* – nettle or sting cells)

Peyssonel (1723) and **Trembley** (1744) proved Cnidarians to be animals. **Leuckart** used the term "coelenterata". **Hatschek** (1888) used the term "cnidaria". The phylum Cnidaria includes about 9,000 species.

General Characters

1. **Habitat.** All are aquatic and are mostly marine, except a few like *Hydra,* are fresh water.

2. **Body Form.** Body form varies considerably. Many colonial cnidarians like *Obelia* (Fig. 4.15) are **trimorphic**, having three kinds of **zooids — polyps, blastostyles** and **medusae.** Occurrence of more than one type of individuals in their colonies performing different functions is called **polymorphism.**

3. **Symmetry.** They show **radial** symmetry.

4. **Germ Layers.** Cnidarians are **diploblastic animals,** *i.e.*, derived only from two embryonic germ layers, *viz.*, ectoderm and endoderm.

5. **Level of Organization.** They are the first multicellular animals from evolution point of view which show **tissue level of organization.**

6. **Body wall** (Fig. 4.12). The body wall consists of two layers of cells; outer **epidermis** and inner **gastrodermis**. There is a non-cellular gelatinous layer, called **mesogloea,** between the epidermis and the gastrodermis.

1. **Epidermis.** The epidermis consists of the following cells. (i) **Epitheliomuscular cells**. They provide protection and act as muscles. (ii) **Cnidoblasts (= stinging cells)**. Name of the phylum Cnidaria is due to the presence of these cells. A cnidoblast (also called **nematoblast**) has **nematocyst ('stinging organ')**. The nematocyst consists of **capsule**, **shaft** and **thread tube** (Fig. 4.13). The nematocysts are used for defence and offence. (iii) **Interstitial cells**. They are reserve cells and are called **totipotent cells** which can be converted into any type of cells. (iv) **Nerve cells**. They form a **primitive nervous system.** (v) **Sensory cells**. They are sensory in function.

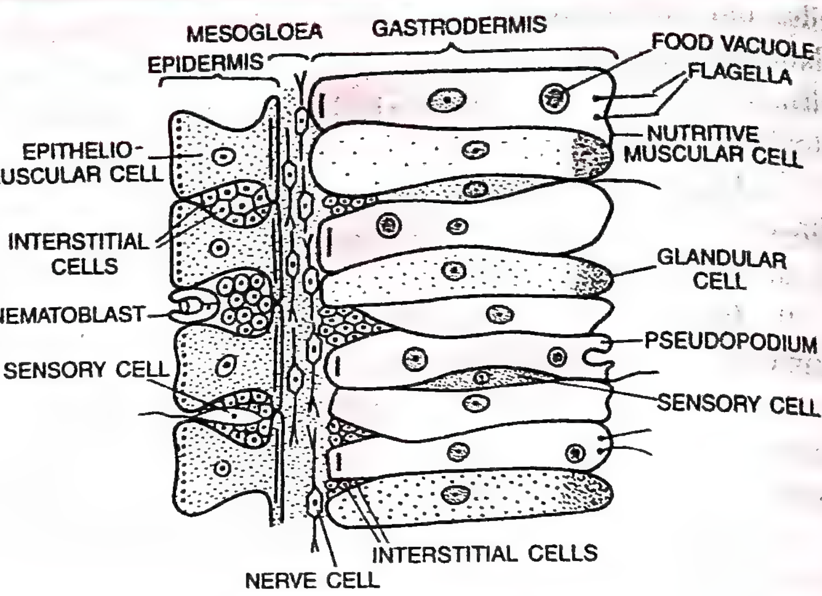


Fig. 4.12. L.S. Body wall of *Hydra*.

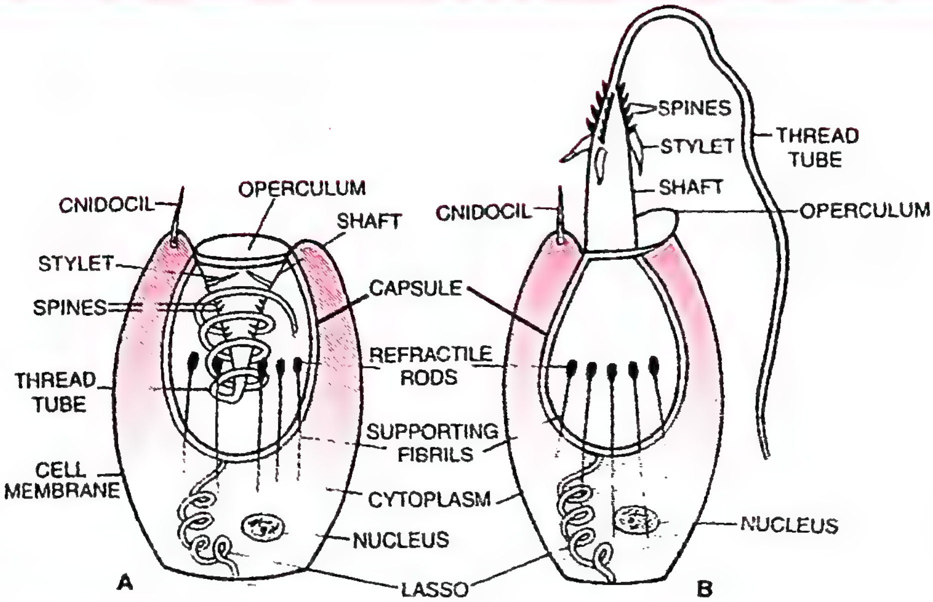


Fig. 4.13. Cnidoblasts. A, Undischarged; B, Discharged.

Differences between Nematoblast and Nematocyst	
Nematoblast (cnidoblast)	*Nematocyst*
1. It is a cell present in the epidermis.	1. It is a structure present inside the nematoblast.
2. It is called "stinging cell".	2. It is called "stinging organ".
3. It consists of cell membrane, cytoplasm, nucleus, nematocyst, etc.	3. It consists of capsule, shaft and thread tube. It is used for defence and offence.

2. **Gastrodermis.** The gastrodermis comprises (i) **Nutritive muscular or digestive cells.** Intracellular digestion takes place inside these cells. They also act as muscles; (ii) **Gland cells.** They secrete digestive enzymes for extracellular digestion; (iii) **Interstitial cells**; (iv) **Nerve cells** and (v) **Sensory cells.** Functions of interstitial cells, nerve cells and sensory cells are similar to the cells found in epidermis.

7. **Digestive Tract.** Cnidarians have a central **gastrovascular cavity (coelenteron)** with a mouth, which also acts as anus. Thus there is present **incomplete** digestive tract.

8. **Digestion.** Both **intra-** and **extra-cellular digestion** are present.

9. **Respiration** and **excretion** are carried out through body surface by diffusion. Ammonia is chief excretory waste.

10. **Primitive Nervous System.** A primitive form of 'Nervous system' is found in these animals. It consists of a network of nerve cells and their processes. **Statocyst** is a sense organ for balance which is first time developed in cnidaria.

11. **Skeleton.** In some coelenterates the body is supported by horny or calcareous exoskeleton or endoskeleton.

12. **Reproduction.** Reproduction is both by asexual (budding) and sexual methods. Both gonads and buds arise from the interstitial cells. The power of **regeneration** is also developed.

13. **Development.** The cleavage is **holoblastic.** Direct or indirect development is found. In *Obelia* **planula** larva is present. However in *Aurelia* planula, **scyphistoma** and **ephyra** larvae are found.

14. **Metagenesis.** In *Obelia,* polyps reproduce medusae asexually and medusae form the polyps sexually. Such alternation of asexual and sexual phases in the life cycle of *Obelia* is called **metagenesis.** It should not be confused with alternation of generations as found in plants where one phase is haploid and other is diploid. Here both phases are diploid.

Unique Features. (i) Presence of cnidoblasts for defence and offence. (ii) Network of nerve cells acting as "Primitive Nervous System."

Advancement over Sponges. (i) Tissue level of organisation. (ii) Digestive tract. (iii) Nerve cells and sensory cells.

Classification

Chiefly on the basis of the dominance of medusoid or polypoid phase in the life cycle, the phylum Cnidaria is divided into three classes.

Class 1. Hydrozoa (Gk. *Hydros*– water, *zoon*– animal). Either only polyps are found or polyps and medusae are present. **Examples** : *Hydra, Obelia* (sea-fur) and *Physalia, Porpita, Velella, Millepora* (hydroid coral).

Class 2. Scyphozoa (Gk. *skyphos*– cup). They are represented by medusae. **Examples:** *Aurelia, Rhizostoma*

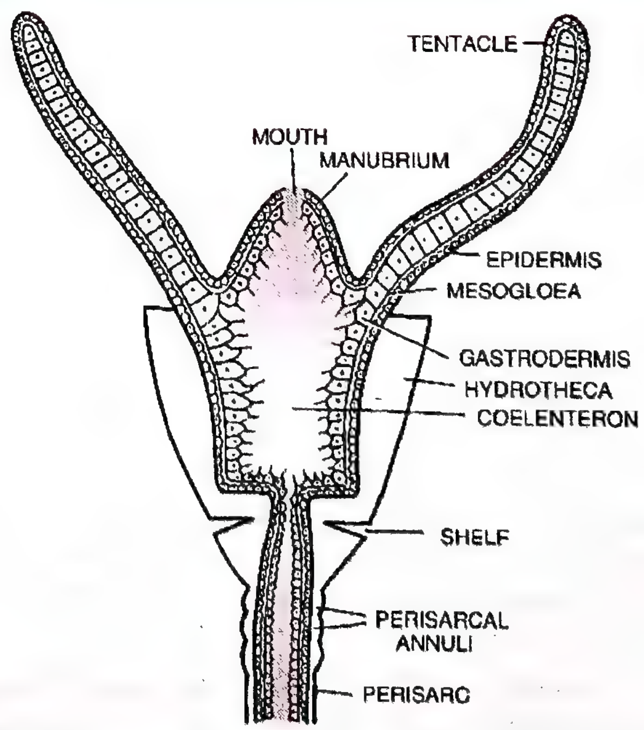


Fig. 4.14. L.S. Polyp.

Class 3. Anthozoa* (Gk. *anthos*– flower). They are represented by the polyp form. Medusa form is absent. **Examples :** *Gorgonia*, *Adamsia*, *Alcyonium* (dead man's finger), *Fungia* (mushroom coral), *Pennatula*, *Corallium* (red coral), *Astraea*, *Meandrina*, *Madrepora* (stag-horn coral), *Tubipora* (organ pipecoral).

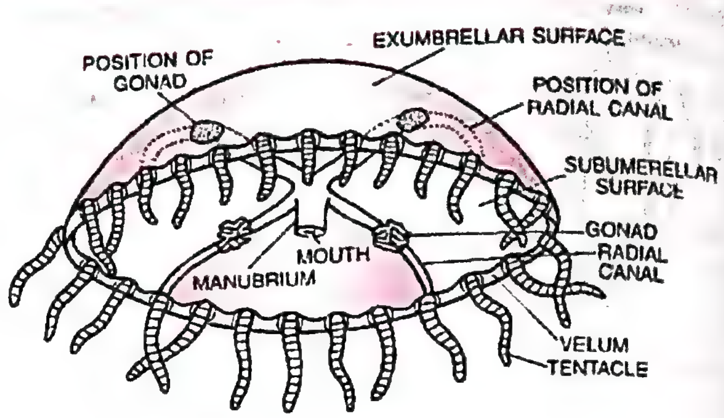


Fig. 4.15. Side view of Medusa.

Hydra. *Hydra* is a fresh water coelenterate and is carnivorous. *Hydra has great power of regeneration* which was first discovered by **Trembley** (1774). Both bisexual and unisexual *Hydras* are found. A unicellular green alga *Zoochlorella* lives in nutritive muscular cells of *Hydra viridissima* (Green Hydra). The alga utilizes metabolic wastes of host cells like CO_2, water, etc., for photosynthesis. The host *Hydra* is benefitted by utilizing O_2 released in photosynthesis by the alga. Such association by which both organisms are mutually benefitted is called **symbiosis**. *Hydra oligactis* (brown Hydra), *Hydra vulgaris* (colourless *Hydra*) and *Hydra gangetica* (pinkish white Hydra) are some other species.

***Obelia* — The Sea Fur.** Obelia is polymorphic. The three types of individuals are **polyps**, **blastostyles** and **medusae**. The polyps are mainly nutritive in function, while the blastostyles give rise to reproductive individuals, the medusae by budding. The medusae contain gonads for sexual reproduction. *Obelia* is carnivorous.

Differences between Polyp and Medusa (Fig. 4.14 & 4.15)

Polyp	*Medusa*
1. Polyp is a fixed.	1. Medusa is free swimming.
2. Polyp is cylindrical in shape.	2. Medusa is an umbrella like and formed by blastostyle.
3. Sense organs are absent.	3. There are 8 sense organs called the **statocysts**, each is meant for equilibrium.
4. Polyps are without gonads.	4. Medusa has four gonads.
5. Polyps feed and protect the colony	5. Medusa brings about sexual reproduction and dispersal of species.
6. Polyp belongs to asexual generation.	6. Medusa represents the sexual generation.

***Physalia*— The Portuguese-man-of-war.** A gas gland present inside the pneumatophore secretes a gas which helps the animal to float over the water surface. Physalia exhibits a remarkable example of *polymorphism* and *division of labour*. Just below the pneumatophore are hanging down the three types of zooids and tentacles. (i) **Dactylozooids** serve in catching the food and are also the organs of defence. (ii) **Gastrozooids** are nutritive zooids. (iii) **Gonozooids** are reproductive zooids. The poison of dactylozooids is neurotoxic which is very harmful.

Velella — The **"Sail-by-the wind"**. It also shows polymorphism. The pneumatophore is flat and contains air and bears a vertical **sail** on the top. The sail drives the colony along

* Also called Actinozoa.

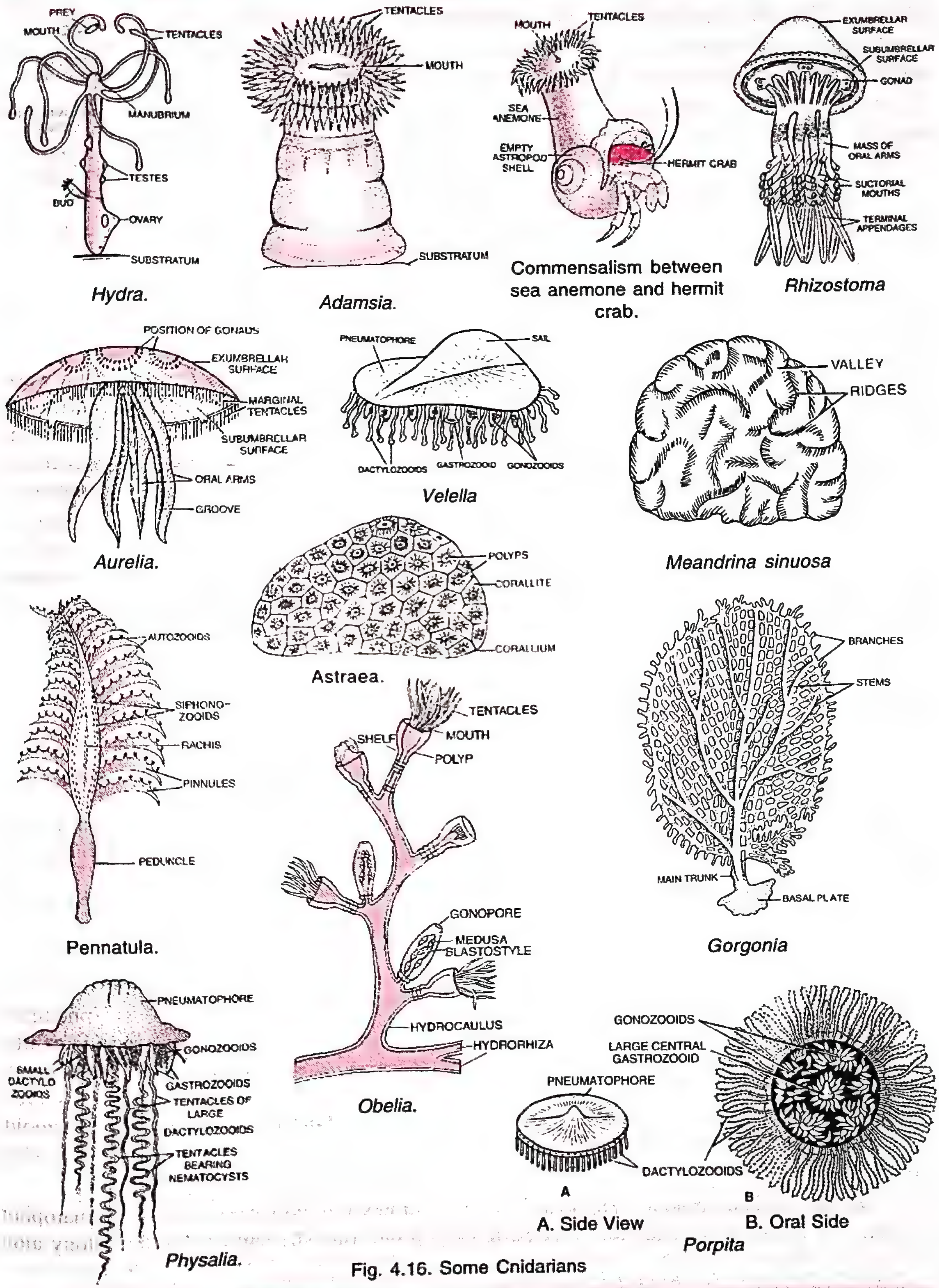


Fig. 4.16. Some Cnidarians

the wind. On the lower side, a single large **gastrozoid** bears mouth. The **gonozooids** bear medusae. The margin of the disc has **dactylozooids** bearing nematocysts.

Porpita **—** It also shows polymorphism. *Porpita* resembles *Velella* except that it does not have sail and has a circular disc-like pneumatophore.

***Aurelia*— The Jelly fish.** The body of *Aurelia* is somewhat similar to that of the medusa of *Obelia*. There are present four large tapering *oral* arms. *Aurelia* is unisexual bearing four gonads (ovaries or testes) in the subumbrellar side.

***Rhizostoma* — The Jelly fish.** The umbrella shaped body is without marginal tentacles. Numerous mouths are present on the oral arms. The oral arms are bifurcated distally to form eight long terminal appendages.

***Adamsia*— The Sea anemone.** Adamsia is found attached to the empty shell of gastropod (mollusc) occupied by hermit crab (genus *Eupagarus*). It shows **commensalism.** The association between *Adamsia palliata* and *Eupagarus prideauxi* (hermit crab) is a classical example of commensalism. Commensalism is a relationship between two living individuals of different species in which one is benefitted while other is neither harmed nor benefitted except to a negligible extent. *Adamsia* is transported from one place to the other by hermit crab which lives inside the shell.

***Astraea* — The Star coral.** The polyp possesses a basal cup of calcium carbonate known as **corallite** (skeleton of polyp). The corallite is secreted by the epidermis of the polyp. The exoskeleton of the whole colony is called **corallium.**

***Meandrina sinuosa*— The Brain Coral.** *Meandrina* bears on its surface long winding **valleys** separated by ridges. The valleys are occupied by **compound polyps** which are formed from ordinary polyps. The surface of the colony is marked by convolutions (fissures) as found in the human brain. That is why *Meandrina sinuosa* is called 'the brain coral.'

***Pennatula*— The Sea pen or Sea feather.** The sea pen looks like a quill (a type of feather). Pennatula is carnivorous and phosphorescent. The colony is **dimorphic** (two types of zooids), (i) **Siphonozooids**, found on the sides of the **rachis** on the dorsal side, cause circulation of water in the canals of the colony. (ii) **Autozooids** are nutritive in function and lie in a single row on each **pinnule**.

***Gorgonia*— The sea fan**. All the branches form a hand-held fan-like network. *Gorgonia* is dimorphic. The zooids are of two types : **autozooids** for feeding and **siphonozooids** for driving a current of water through the colony.

ADDITIONAL INFORMATION

- **Corals.** The corals are hard materials secreted by the tiny living polyps of some colonial cnidarians in the sea. The corals are of two main kinds :

  (1) **Hydrozoan corals**. The polyps of a few colonial hydrozoans form such corals. Example *Millepora.*

  (2) **Anthozoan corals.** The anthozoans form many kinds of corals : (i) **Soft corals.** Example : *Alcyonium* (Dead man's finger). (ii) **Horny corals.** Example : *Gorgonia* (sea fan). (iii) **Blue corals.** Example : *Heliopora.* (iv) **Red corals** : Example : *Tubipora* (organ pipe coral) and *Corallium* (red coral). *Corallium nobile* (Moonga) is used in jewellery hence it is also called precious coral. (v) **True** or **Stony Corals.** Examples : *Fungia* (mushroom coral), *Madrepora* (stag-horn coral), *Astraea* (Star coral) and *Meandrina* (brain coral). They are the major builders of the coral reefs.

- **Coral Reefs.** A coral reef is a ridge or mound in a shallow, tropical sea, has its upper surface near the surface of water, supports a variety of animals and plants and is formed of calcium carbonate produced by some of its inhabitant, chiefly medreporarian corals. *Coral reefs form stable marine ecosystems.* The coral reefs are of three kinds :

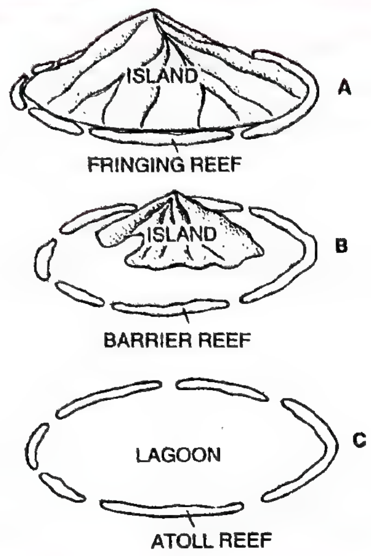


Fig. 4.17. Different types of coral reefs.

(i) **Fringing reefs**. The coral reefs lie close to the shores of island (A body of land completely surrounded by water). **Hawaiian islands,** in the North pacific ocean under the U.S.A, are an ideal example of permanent fringing reefs. (ii) **Barrier reefs**. They are formed away from the shore. The body of water separates the barrier reefs from land. **Australia's Great Barrier Reef** is an example of such a reef which is over 1920 km long about 80 km wide at certain places and about 145 km from the sea shore. The Great Barrier Reef lies along the north-east coast of Australia. (iii) **Atoll reefs.** An atoll reef is horse shoe shaped reef that surrounds a **lagoon** (water enclosed by an atoll reef) but not an island. It may be complete or broken by a number of channels . The Lakshadweep and Maldive islands in the Indian Ocean are composed of Atoll reef. Thus Lakshadweep (a union territory of India) is coral Island of India.

- The Pacific Ocean contains more coral formation than any other ocean.
- Totipotent interstitial cells is the characteristic of *Hydra*.
- *Hydra* was discovered by **Leeuwenhoeck** (1703). Its name was given by **Linnaeus** (1758).
- ***"Sea Wasp'*** – a cnidarian is one of the most poisonous animals.
- In India medusae of *Aurelia* are commonly found in coastal waters of Chennai.
- **Types of nematocysts in *Hydra*.**

1. **Stenoteles** or **penetrants**. These are the **largest.** The thread tube is open at the end. When discharged it releases thread tube by which a poisonous fluid, **hypnotoxin** (chemically protein and phenols) is injected paralysing the prey.
2. **Holotrichous isorhizas** or **Large glutinants** or **streptoline glutinants**. They have a narrow butt. The thread is open at the tip. There are small spines on the butt and thread. They stick to the surface of the prey.

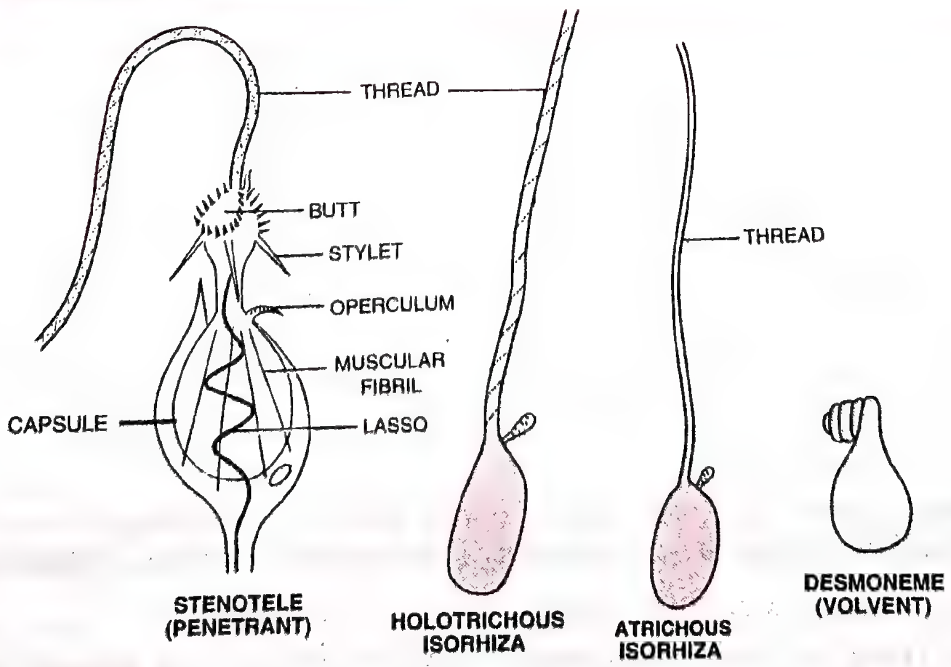


Fig. 4.18. Discharged nematocysts of *Hydra*.

3. **Atrichous isorhizas** or **small glutinants or stereoline glutinants.** Butt is absent. Thread is open at the tip and it has no spines. These trichocysts fix the object when *Hydra* walks on its tentacles.

4. **Desmonemes** or **Volvents**. There is no butt. This nematocyst contains a short, thick spineless thread tube which forms a single loop and is closed at the tip. On being discharged, these nematocysts are used to capture the prey.

- Thus penetrants and volvents are of particular value in capturing the prey, however, glutinants secrete a sticky substance used in locomotion by fastening the tentacles to solid objects.
- ***Corallium rubrum*** (red coral) has been used widely in jewellery and known as **red moonga**.
- Stimulation for discharge of nematocyst is first mechanical then chemical.
- Myonemes are present in muscular processes of epitheliomuscular and nutritive muscular cells.
- Mesenteries are the soft internal partitions of a coral polyp or sea anemone.

Phylum Ctenophora—The Comb Jellies or Sea Walnuts

(Gk. *ktene*– comb, *phors*– bearing)

The ctenophores as a distinct group were first recognized by **Escscholtz** (1829).

General Characters

There are about 50 species of ctenophores.

1. **Habitat.** All ctenophores are exclusively *marine.*

2. **Habits.** They feed on plankton, swim by cilia. Power of *regeneration is well marked.* **Bioluminescence** (the property of living organism to emit light) is well-marked in ctenophores.

3. **Body Form.** Body form is variable.

4. **Symmetry.** Symmetry is **biradial** (radial + bilateral). The arrangement of comb plates gives the appearance of radial symmetry, the tentacles and branching of gastrovascular canals are of bilateral type.

5. **Germ Layers.** They are **diploblastic** having ectoderm and endoderm.

6. **Level of Organisation.** Tissue level of organization is present.

7. **Appendages.** Tentacles may or may not be present. When present, they are two in number.

8. **Body Wall.** The body wall consists of outer **epidermis**, inner **gastrodermis** and middle **mesogloea** (= **collenchyma**). The mesogloea is different from that of cnidaria as it contains amoebocytes, elastic fibres and muscle cells. From this reason ctenophores may be considered as "triploblastic". Special adhesive cells called **colloblasts** (= **lasso cells**), are present in the epidermis of tentacles which help in food capture. The ctenophores do not have nematocysts except *Euchlora rubra. Euchlora rubra* has nematocyst on tentacles. It does not have coloblasts. The presence of nematocysts in this species is an evidence of the cnidarian origin of the ctenophores.

9. **Locomotion.** Comb like eight ciliary plates called **comb plates** are present on the body. The cilia of these plates help in swimming. Ctenophores are hence called **comb Jellies.**

10. **Body Cavity.** They are acoelomates.

11. **Digestive Tract** (= **Gastrovascular tract**). It consists of **mouth, pharynx** or **stomodaeum, stomach** or **infundibulum, anal canals** and two **anal pores**. The stomach is highly branched to form a complex system of **gastrovascular canals**. Since there are

mouth and anal pores, the digestive tract is mostly **incomplete.** Digestion is both **extra-cellular** and **intracellular.**

12. Skeletal, circulatory, respiratory and excretory systems are absent.

13. **Nervous System.** The nervous system is diffused as in cnidarians.

14. **Sense Organ.** The aboral end (opposite end of mouth) bears a sense organ, called **statocyst** for equilibrium (balance).

15. **Reproduction.** They are monoecious (= hermaphrodite or bisexual). Fertilization is generally external. Asexual reproduction is not present. Paedogenesis is common.

16. **Development.** Egg contains yolk, hence called **lecithal.** Yolk is initially accumulated at the centre (**centrolecithal** condition) but later on when cleavage starts yolk shifts to one side (**telolecithal** condition). Cleavage is complete, holoblastic, unequal, biradial and determinate (a complete embryo is formed if all the blastomeres remain together). Gastrulation occurs by epiboly. The development is indirect with a ciliated spherical **cydippid larva.**

Unique Features. (i) Comb like ciliary plates for swimming. (ii) Special adhesive cells, the colloblasts for capturing the prey. (iii) Mesogloea with amoebocytes and smooth muscle cells. (iv) Two anal pores.

Advancement over Cnidaria. (i) Independent muscle cells. (ii) Complete digestive tract. (iii) Determinate Cleavage.

Classification

The phylum Ctenophora is divided into two classes: Tentaculata and Nuda.

Class 1 Tentaculata. They have tentacles and small stomodaeum. Examples: *Hormiphora* (The Sea Walnut), *Pleurobrachia* (The Sea gooseberry). *Ctenoplana, Cestum* (The Venus' Girdle).

Class 2 Nuda. Their body is without tentacles. They have spacious mouth and stomodaeum. Example : *Beroe.*

***Pleurobrachia* — The Sea gooseberry.** *Pleurobrachia* reproduces only sexually. Life history includes a **cydippid larva**. Power of regeneration is well marked. The tentacles bear special adhesive cells, the **lasso cells** or **colloblasts** which help in food capture. The broad end called aboral pole, contains the **anal canals, anal pores** and a sense organ, the **statocyst**. The animal is hermaphrodite.

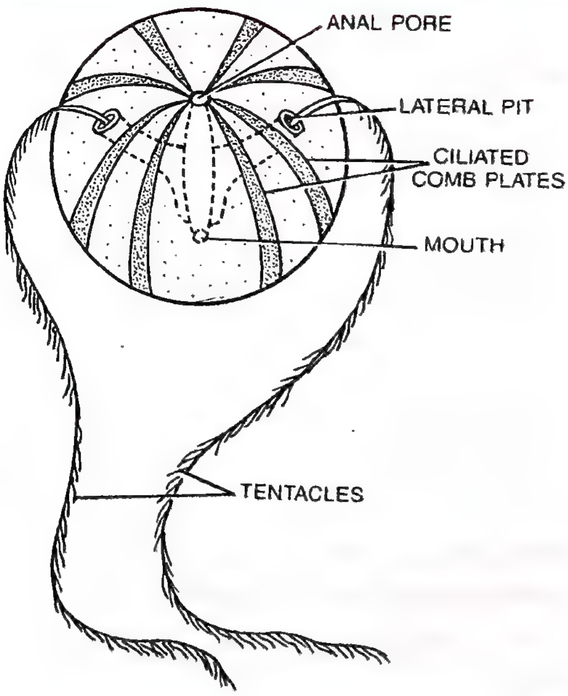


Fig. 4.19. *Pleurobrachia.*

Phylum Platyhelminthes— The Flat worms

(Gk. *platys*– broad or flat; *helmin*– worm)

Gegenbaur (1859) placed flat worms in a separate group and gave the term **Platyhelminthes.** The phylum Platyhelminthes includes about 13,000 species.

General Characters

1. **Habitat.** The flat worms are mostly **parasites** but some flat worms are free-living (terrestrial, fresh water or marine).

2. **Body form.** The body is dorso-ventrally flattened and is without true segments.

3. **Symmetry.** They show bilateral symmetry.

4. **Germ Layers.** From the evolution point of view, they are the first **triploblastic** animals, *i.e.*, consisting of three germ layers : ectoderm, mesoderm and endoderm.

5. **Level of Organization.** The flatworms have **organ level of organisation.**

6. **Body wall.** The body covering is soft and may or may not be ciliated. Rod shaped bodies, the **rhabdites** are present in the epidermal cells of the living Platyhelminthes. They are protective and used in food capture.

7. **Body cavity.** The space between the body wall and organs is filled with a peculiar connective tissue, called the **parenchyma.** The parenchyma helps in transporting the food materials. Flat worms are **acoelomates** (without coelom).

8. **Digestive Tract.** The digestive tract, if present, is incomplete (without anus). Digestive tract is absent in tapeworms.

9. **Skeletal, respiratory** and **circulatory systems** are absent. The fluid in the parenchymal network maintains the body shape. It is called **hydroskeleton.** Gaseous exchange in aerobic flat worms occurs by diffusion through body surface.

10. **Excretory system.** It consists of peculiar **flame cells (solenocytes/protonephridia)** which are meant for excretion and osmo-regulation. Ammonia is chief excretory waste.

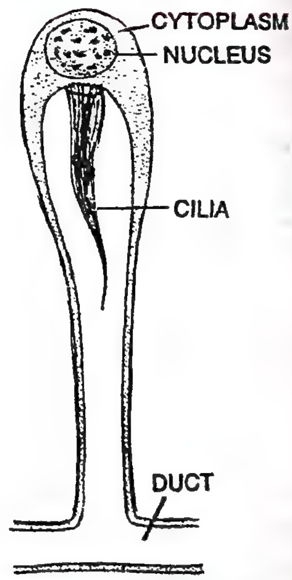


Fig. 4.20. Flame cell.

11. **Nervous System.** The nervous system is **ladder-like.** It consists of the brain and two main longitudinal nerve cords connected at intervals by transverse commissures.

12. **Reproductive System.** These animals are generally hermaphrodite, and the reproductive organs are well developed. The fertilization is cross and internal. *In tapeworms self fertilization is found.* Asexual reproduction by **transverse binary fission** occurs in some flat worms.

13. **Development.** Life cycle is complicated in most flat worms with one or more larval stages. In liver fluke **miracidium, sporocyst, redia, cercaria** and **metacercaria** larvae are present. In tapeworm **onchosphere, hexacanth** and **cysticercus** larvae are found.

14. **Regeneration.** It is well marked in some flat worms like *Planaria.*

Unique Features. (i) Parenchyma. (ii) Flame cells. (iii) Ladder-like nervous system. (iv) Self-fertilization occurs in some flat worms (*e.g., Tapeworms*).

Advancement over Ctenophores. (i) Triploblastic. (ii) Organ-system level of organisation. (iii) Gonoducts and copulatory organs.

Classification. Chiefly on the basis of mode of life, phylum platyhelminthes is divided into three classes.

Class 1. Turbellaria (L. *turbella–* stirring). These are mostly free-living flatworms. **Examples.** *Dugesia* (= *Planaria*).

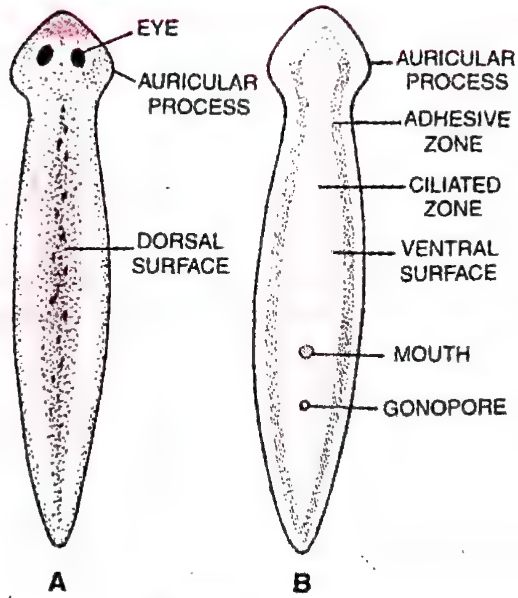
Class 2. Trematoda (Gk. *trema– hole + eidos* = form). These are ecto or endoparasitic

worms (flukes) **Examples.** *Fasciola, Schistostoma, Polystomum* (endoparasite of the urinary bladder of frog and turtles).

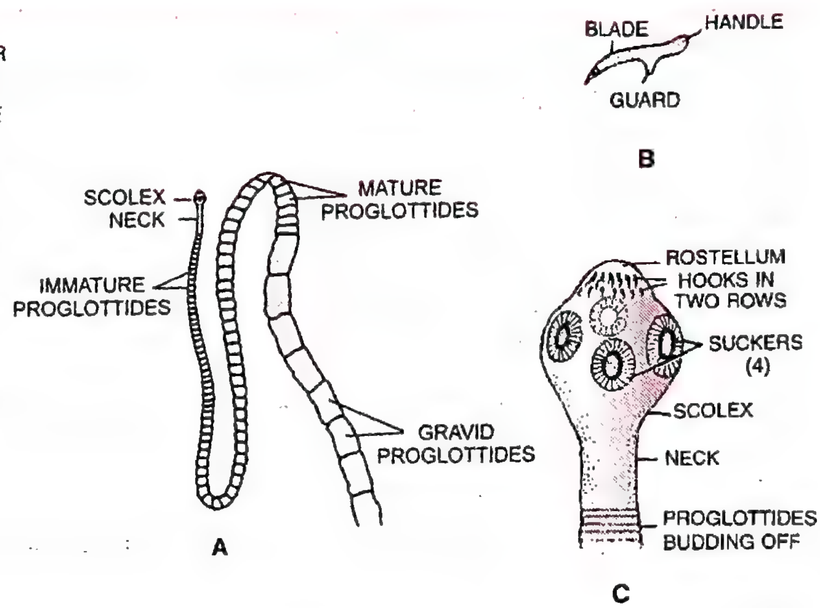
Class 3. Cestoda. (Gk. *kestos– girdle + eidos* = form). These worms are endoparasites of vertebrates. The body is generally divided into a few to many **proglottides** (not true segments). **Examples.** *Taenia, Echinococcus.*

Dugesia **(Planaria).** It is found in slow moving streams or fresh water ponds. It bears cilia on its body. It has a great power of regeneration. The heads bear two lateral lobes, the **auricular processes**, and a pair of **eyes.**

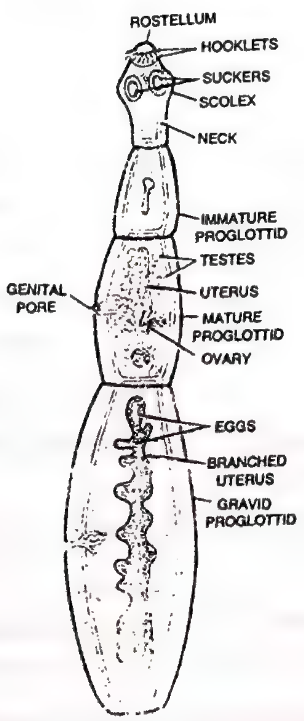
Schistosoma. It is commonly called the **"blood fluke"** as it lives in the hepatic portal system and mesenteric blood vessels of human beings. Its intermediate host is snail. The male carries the female permanently in the **gynaecophoric canal**. *Schistosoma* shows well



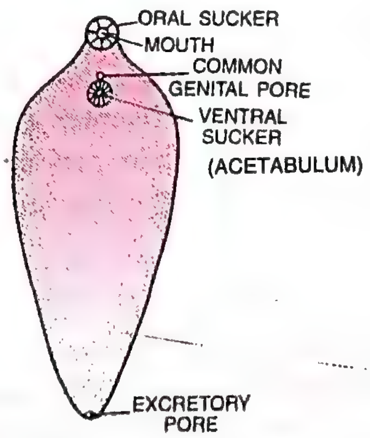
Planaria.
A, Dorsal side; B, Ventral side.



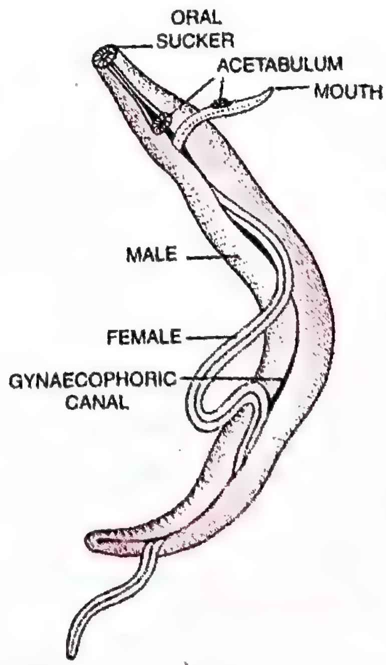
A. Tapeworm; B, Hook; C. Scolex.



Echinococcus granulosus



Fasciola hepatica.



Schistosoma.

Fig. 4.21. Some Flat worms.

marked **sexual dimorphism**. After fertilization the female leaves the male and lays eggs in the smaller blood vessels. *Schistosoma* causes **schistosomiasis.** The symptoms of the disease are diarrhoea, anaemia, enlargement of liver and spleen, pain and fever. The disease can be prevented by not taking contaminated water.

***Fasciola*— The Liver fluke.** Adult *Fasciola hepatica* is found in the liver and bile duct of sheep, goat which are its **primary hosts**. The **secondary** or **intermediate host** is a pond snail (a mollusc) of genus *Limnaea* and genus *Planorbis*. The fluke is hermaphrodite but there is cross fertilization. It causes a disease known as **liver rot (fascioliasis)**. The infected animal feels great muscular weakness resulting in muscular pain. The liver enlarges and the bile ducts are blocked. The disease may prove fatal to the animal. It has **acetabulum.**

***Taenia solium*— The Pork Tapeworm**. It is found in all those countries, where pork is taken as food. The adults of *T. solium* are parasites in the small intestine of human beings **(primary host)** and its larva is mostly found in the muscles of the pig **(secondary host)**. The tapeworm does not have alimentary canal. The digested food of the host is diffused directly through the general body surface. *T. solium* is hermaphrodite. There is self fertilization. The body is divisible into three parts : **scolex, neck** and **strobila**. At the top of the scolex lies a cone like **rostellum**. The rostellum bears at its base about 22–32 small curved chitinous **hooks** placed in two circlets. Hooks of the posterior circlet are somewhat smaller than those of the anterior one. On the middle part of the scolex there are present 4 cup-like muscular **suckers**. The suckers and hooks are the organs of attachment. The strobila consists of immature, mature and gravid proglottides. Proglottides show pseudometamerism (external segmentation only). *Both mouth and anus are absent.*

Tapeworm causes **taeniasis**. This disease can be characterized by such symptoms as abdominal pain, restlessness, anaemia, false appetite and indigestion.

Cysticercosis caused by **cysticercus** (bladder worm) is more dangerous than taeniasis. Cysticercus is a larva of tapeworm which develops from another larva, the **onchosphere**. Sometimes, the onchospheres reach human stomach directly with contaminated food and water or by antiperistalsis of intestine. These onchospheres develop into bladder worms in man and thus, man become accidently intermediate host of the tapeworm. The bladder worms may reach the eyes where they may undergo encystment and cause blindness or in the brain they can cause epilepsy.

***Taenia saginata* (Beef tapeworm)**. It lives in the human intestine of beef eating persons. Its intermediate hosts are cattle and buffaloes. It is longer than *Taenia solium*. Its body is divisible into scolex, neck and strobila. The scolex bears four adhesive suckers but it does not have rostellum and hooks. Its infection occurs by taking under-cooked beef.

Comparison between Immature, Mature and Gravid Proglottides of a Tapeworm

Immature Proglottides	*Mature Proglottides*	*Gravid Proglottides*
1. Reproductive organs are not developed.	Both male and female reproductive organs are well developed.	Reproductive organs are obliterated.
2. Uterus is not present.	Uterus is small and unbranched.	Uterus is branched and filled with capsules (containing fertilized eggs).
3. There is no shedding of proglottides.	There is no shedding of proglottides.	There is shedding of proglottides called **apolysis**.

***Echinococcus granulosus* – The dog tapeworm** or **hydatid worm**. It lives as an endoparasite in the intestine of dogs, cats and foxes, etc. Man sometimes serves as an incidental

host. The dog tapeworm consists of a **scolex, neck** and **strobila. Strobila** consists of 3 or 4 proglottides : one immature, one or two mature and one very large gravid. Man acquires infection by playing with pet dogs. The hydatid worm causes **hydatid disease** in man. Presence of cysts of this worm in the brain and kidney may prove fatal.

Peculiar Features that you find in Parasitic Platyhelminthes

(1) The thick tegument (body covering) resistant to the host's digestive enzymes and anti-toxins. (2) Adhesive organs like suckers in flukes and the hooks and suckers in tapeworms for a firm grip on or in the host's body. (3) Loss of locomotory organs. (4) Digestive organs are absent in tapeworms because digested and semidigested food of the host is directly absorbed through the body surface. (5) There is total absence of sense organs in parasitic flatworms. (6) Reproductive system is the best developed in parasitic flatworms. They are mostly hermaphrodite. In some parasitic flatworms like tapeworms self fertilization takes place. Thus large number of eggs are produced. (7) Parasitic flatworms, such as liver fluke and tapeworms perform anaerobic respiration. (8) They possess a considerable osmotic adaptabiliy, as they can successfully live in different media. (9) A fertilized egg, along with one or more yolk cells is covered by a resistant shell, which is protective in function.

ADDITIONAL INFORMATION

- **Brief Life Cycle of Liver Fluke.** (*Fascioha hepatica*)

Adult fluke in the liver of sheep or goat
→ Capsules containing zygotes
→ Zygote gives rise to **Miracidium** (1st Larva)
→ Miracidium enters the snail
→ Miracidium changes to **Sporocyst** (2nd Larva)
→ Sporocyst produces **Rediae** (3rd larvae) by parthenogenesis (paedogenesis)
→ Redia produces **Cercariae** (4th larvae) by parthenogenesis (paedogenesis)
→ Cercariae come out of the snail
→ Cercariae change to **Metacercariae** (5th Larvae)
→ Metacercariae get attached to water weeds
→ Weeds and Metacercariae are eaten by sheep or goat
→ Metacercaria changes to young fluke
→ Adult fluke in the liver of sheep or goat

- **Brief Life Cycle of Tapeworm** (*Taenia solium*).

Adult tapeworm in human gut
→ Fertilized ova (zygotes) in the mature proglottides
→ Capsules containing zygotes in gravid proglottides
→ **Onchospheres** (larvae) in the gravid proglottides
→ Onchospheres in human faeces (outside the body)
→ Faeces containing onchospheres is eaten by pig
→ Each onchosphere contains a **hexacanth**
→ Hexacanths penetrate the gut of the pig
→ Hexacanths in the blood of pig
→ Hexacanths in the muscles of pig
→ Hexacanths develop into **cysticerci** (larvae)
→ Cysticerci in the human gut
→ Each cysticercus develops into young tapeworm in the human gut
→ Adult tapeworm in human gut

- Tapeworms are said to be "Wallowers" because they absorb nourishment through their body surface.
- *Fasciolopsis buski* is Human Intestinal fluke.
- Laurer's canal (acts as uagina) and Mehlis's glands (their secretion lubricates the passage) are present in female reproductive system of liver fluke

Phylum Aschelminthes or Nemathelminthes — The Round worms

(Gk. *nema*– thread, *helmin*– worm)

Gegenbaur (1859) proposed the term '**Nemathelminthes**'. The phylum Nemathelminthes includes about 15,000 species.

General Characters

1. **Habitat.** Many roundworms live as parasites in plants and animals. They cause serious agricultural, veterinary and human health problems. Round worms are also free living and occur in fresh water, sea water and soil.

2. **Body Form.** They are called round worms because they appear circular in cross section. They are unsegmented.

3. **Body wall.** It consists of firm, non living resistant **cuticle**, **syncytial epidermis** (a continuous layer of cytoplasm with scattered nuclei) and **muscle layer.**

4. **Body cavity.** The body cavity is called **pseudocoelom** because mesoderm is found as scattered pouches in between the ectoderm and endoderm.

5. **Digestive Tract.** Alimentary canal is **complete** with **muscular pharynx**.

6. **Skeletal, respiratory** and **circulatory** systems are absent. **Pseudocoelomic fluid** present in the pseudocoelom maintains body shape and forms **hydroskeleton.** Gaseous exchange in aerobic respiration occurs by diffusion through the body surface. The pseudocoelomic fluid transports materials.

7. **Excretory System.** The excretory system consists of gland cells, or of canals or of both. In *Ascaris*, 'H' shaped excretory system of canals and complicated "giant cell" called "**renette cell**" is present. Ammonia is main excretory matter. However, *Ascaris* also excretes urea.

8. **Nervous System.** It consists of a **circumpharyngeal ring** that gives rise to nerves forward as well backward.

9. **Sense Organs.** (i) **Papillae** (raised structures) occur on the lips, on the sides of anterior end in both male and female and in front and behind the cloacal apperture. All papillae are tactile in function. (ii) **Amphids** (pits) are present on the lips and are chemoreceptors. (iii) **Phasmids** are unicellular glands located upon lateral sides of the posterior end and are glandulosensory in nature.

10. **Sexes**. Sexes are separate (**dioecious**). Generally they show **sexual dimorphism**, often females are longer than males. Fertilization is internal. There is no asexual reproduction.

11. **Development**. Development may be direct or indirect. During indirect development a larva is present. **Filariform** larva is present in *Ancylostoma* (hook worm), **microfilaria** larva is found in *Wuchereria* (filarial worm) and **Rhabditiform** larva is present in *Ascaris* and *Enterobius* (pin worm).

Unique Features. (i) Syncytial epidermis. (ii) Muscle layer of body wall consists of longitudinal fibres only. (iii) Pseudocoel.

Advancement over Flatworms. (i) Pseudocoel. (ii) Complete digestive tract. (iii) Unisexual condition.

Classification. Aschelminthes is classified into two classes : Aphasmidia and Phasmidia.

Class 1. Aphasmidia. (i) Phasmids are absent. (ii) Amphids are of various types. Examples : *Trichinella,* (Trichina worm), *Trichuris* (Whip worm), etc.

Class 2. Phasmidia. (i) Phasmids are present near hind end of body. (ii) Amphids are present near anterior end. Examples : *Ascaris* (Giant intestinal round worm), *Enterobius* (Pin worm), *Ancylostoma* (Hook worm), *Wuchereria* (Filarial worm), etc.

***Rhabditis*.** This genus includes free living and semi-parasitic forms. *Rhabditis maupasi* lives in soil. The male has **copulatory bursa** at the posterior end of the body.

***Ascaris lumbricoides*— The Giant Intestinal Roundworm.** *Ascaris lumbricoides* is an endoparasite of the small intestine of human beings. It is more common in children. The adult worms live for about 1 to 2 years. There is no secondary host in the life cycle of this parasite.

The mouth of *Ascaris* is bounded by three lips: one **dorsal** and two **ventrolateral**. The dorsal lip has two double papillae, while each ventrolateral lip has one double papilla, one simple lateral papilla and a **amphid**. Papillae are **tactile** (respond to touch). Amphids are **chemoreceptors** (respond to chemicals). The animal shows **sexual dimorphism**. The **phasmids** are a pair of unicellular glands that open outside on the lateral sides of the tail. These are **glandulosensory** in nature.

Differences between male and female Ascaris

Male	*Female*
1. It is smaller than female.	1. It is larger than male.
2. Posterior end is curved.	2. Posterior end is straight.
3. A cloaca, for receiving anus and genital opening is present. The cloaca opens outside through cloacal aperture.	3. There are separate anus and genital aperture. No cloaca is present.
4. Two equal chitinous spicules (pineal setae) project through cloacal aperture.	4. Spicules (pineal setae) are absent.

Above mentioned points clearly indicate the sexual dimorphism in *Ascaris*.

It causes the disease, **ascariasis**. Since a large number of adult *Ascaris* worms normally infest a single host, they obstruct the intestinal passage and thereby cause abdominal discomforts, like colic pains. The patient may also suffer from impaired digestion, diarrohea and vomiting. In children, where the *Ascaris* infection is quite common, mental efficiency is affected and body growth is retarded.

The disease can best be treated by administering antihelminthic drugs such as oil of Chenopodium, Alcopar, Bendex, Dewormis, Mebex, Pantel, Parid, Wormin, Zentel, etc.

***Ancylostoma duodenale*— The Hook worm.** It is found as an endoparasite in the small intestine of human beings. No intermediate host is required. Its larvae enter the human body from moist soil by boring through the skin of the feet. It causes **ancylostomiasis** disease.

***Wuchereria* (Filaria)— The Filarial worm.** Adult *Wuchereria bancrofti* lives as an endoparasite in the lymphatic vessels and lymph nodes of human beings (primary host). The mosquito (certain species of *Culex*) is the intermediate host. Thus its life cycle is **digenetic**. It is **viviparous**. In the lymph glands, the juveniles develop into adults. The accumulation of these worms blocks the lymphatic system resulting inflammation of lymph nodes. It causes a serious disease known as **elephantiasis (= Filariasis)** in the legs, arms, scrotum, etc. Larva of *Wuchereria* is called **microfilaria**.

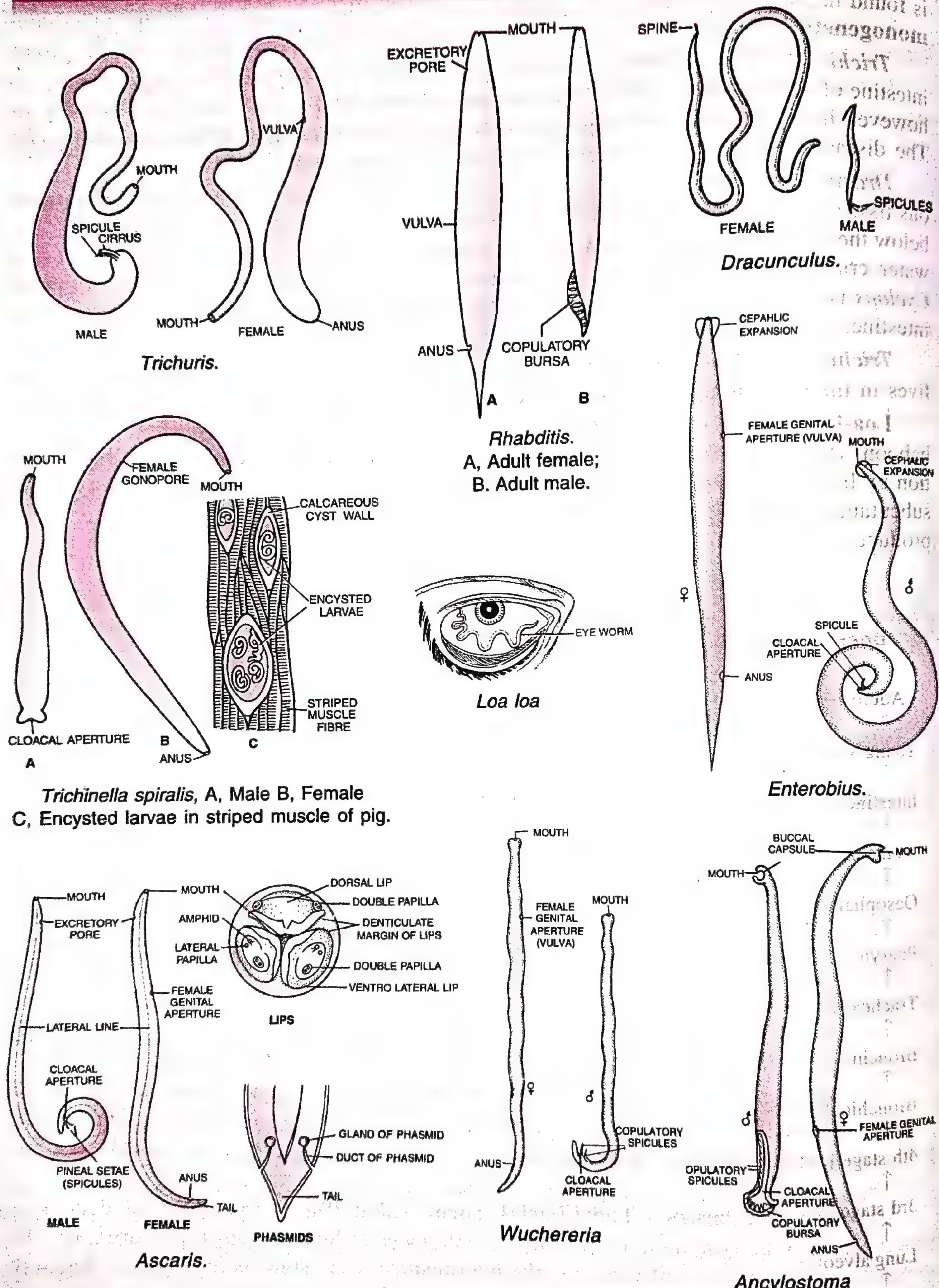


Fig 4.22. Some Round worms.

***Enterobius* (= Oxyuris)— The Pin worm.** *Enterobius vermicularis* (vern.– "Chunna") is found in the caecum, colon or vermiform appendix of the human beings. Its life cycle is **monogenetic.**

Trichinella*— The Trichina worm.** Adult *Trichinella spiralis* is found in the small intestine of human beings and some other mammals like pigs, domestic animals and rodents, however, its encysted larvae are present in the striated muscles of the host. It is ***viviparous. The disease caused by *Trichinella spiralis* is called **trichinellosis.**

***Dracunculus*— The Guinea worm.** *Dracunculus medinensis* occurs in the subcutaneous tissue of man. When the host comes in contact with cold water, the female worm found below the skin, releases larvae in the water. The larvae penetrate the body of *Cyclops*, a fresh water crustacean which is the intermediate host of the guinea worm. When the infected *Cyclops* is taken in by man with water, the larvae escape from the *Cyclops* into the human intestine. The disease caused by this worm is called **dracunculiasis.**

***Trichuris*— The Whip worm.** *Trichuris trichiura* is whip shaped hence it is so named.It lives in the caecum, appendix and colon of man, especially children.

Loa-loa— The Eye worm. *Loa loa* lives in the subdermal connective tissue of man and baboons (large monkeys of Africa and Southern Asia with a dog-like face). Man gets infection by bites of infected deerfly ***chrysops***. Loa loa causes **loiasis**, a disease characterised by subcutaneous swelling (called **calabar swelling**) mostly around the eyes. This parasite may produce conjunctivitis in the eye.

ADDITIONAL INFORMATION

- **Brief Life Cycle of Ascaris.**

Adults → Females → Ova; Adults → Males → Sperms; Ova + Sperms → Fertilized eggs

Fertilized eggs
↓
Out with host faeces
↓
1st stage juvenile in egg— also called **Rhabditiform larva (First mould)**
↓
2nd stage juvenile— also called **embryonated egg** (infective juvenile in egg)
↓
Embryonated egg swallowed by man with food.
↓
2nd stage juvenile free in human intestine
↓
2nd stage juvenile bores through intestinal wall into blood capillaries
↓
Hepatic portal vein
↓
Liver
↓
Hepatic vein
↓
Posterior vena cava
→ Heart
→ Pulmonary artery
↓
Lung capillaries
↓
Lung alveoli
↓
3rd stage juvenile in lung alveoli **(2nd mould)**
↓
4th stage juvenile in lung alveoli **(3rd mould)**
↓
Bronchioles **(4th stage juvenile)**
↓
Bronchi
↓
Trachea
↓
Pharynx
↓
Oesophagus
↓
Stomach
↓
Intestine **(4th mould)**
↓
Young worms
↓
Adults

- **Dual Excretory Waste.** *Ascaris* is both ammonotelic and ureotelic.
- **Monorchic.** Presence of single testis, *e.g.,* Male *Ascaris*.
- **Didelphic.** Presence of two uteri, *e.g.,* Female *Ascaris*.
- *Ancylostoma duodenale* (Hookworm) was discovered in 1838 in an autopsy of an Italian peasant woman by **Dubini.**
- (i) **Rhabdites.** These are rod shaped hyaline bodies which occur in the epidermal cells of turbellarian epidermis. (ii) ***Rhabditis***. It is a free living round worm which lives in soil. (iii) **Rhabditoid** or **Rhabditiform**. It is the larva of *Ascaris*.

Phylum Annelida— the Segmented Animals

(Gk. *annulus*– ring; *lidos*– form)

Lamarck (1801) established phylum **Annelida**. He gave the term Annelida. The phylum Annelida includes over 9,000 species.

General Characters

1. **Habitat.** Annelids occur in fresh water, sea water or moist soil. Some are free living, some are burrowing and a few are parasitic.

2. **Metameric Segmentation.** The annelids are characterised by metameric segmentation, *viz.*, the body is divided externally by ring like grooves the **annuli** (Latin, *annulus* : little ring) and internally by transverse **septa**. The segments are called **metameres.** The first segment is called **peristomium**. An outgrowth, known as **prostomium**, arises from the peristomium.

3. **Setae and Parapodia**. Except leeches, unjointed chitinous **setae** are often present. Some annelids such as *Nereis* have unjointed, locomotory structures, the **parapodia** (*para*– parallel, *podia*– feet).

4. **Body wall**. The body wall consists of thin, and moist non-cellular **cuticle**, single layered **epidermis** and **circular** and **longitudinal muscles**. The muscles are smooth which are highly contractile and help in locomotion.

5. **Coelom (Body cavity)**. A true coelom is present. From evolution point of view, annelids are, perhaps, the first animals to have a true **schizocoelic coelom.** In most annelids coelom is divided by septa into compartments. The coelom is filled with **coelomic fluid** which contains cells.

6. **Hydroskeleton**. The coelomic fluid serves as a hydroskeleton.

7. **Digestive Tract**. It is complete.

8. **Respiratory Organs**. Exchange of gases usually occurs through the skin (**cutaneous respiration**). In some annelids, gaseous exchange also occurs through gills (**branchial respiration**), *e.g., Terebella*.

9. **Blood Vascular System.** It is usually of closed type. Blood is red due to the presence of respiratory pigment **haemoglobin** or **erythrocruorin,** found dissolved in the blood plasma. Free **amoeboid blood corpuscles** are present, but there are no red blood corpuscles. In leech, there is no true blood vascular system, the coelomic space and fluid have been modified to form the circulatory system. It is called **haemocoelomic system** and red coelomic fluid is called **haemocoelomic fluid.**

10. **Excretory System**. It consists of coiled tubular structures, called **nephridia** which help in osmoregulation and excretion. Ammonia is the chief excretory waste.

11. **Nervous system.** The nervous system consists of a **nerve ring** and a solid, double, mid-ventral **nerve cord** with **ganglia**. A ganglion is an aggregation of nerve cells.

12. **Receptors. Tactile receptors** (sensitive to touch), **gustatoreceptors** (receptors of taste) and **photoreceptors** (sensitive to light) are usually found. Some forms have **statocysts** (balancing organs).

13. **Sexes.** Both unisexual (*e.g.*, *Nereis*) and bisexual (*e.g.*, Earthworm, Leech) forms are found.

14. **Development.** It is mostly direct. If there is indirect development (*e.g.*, *Nereis*), it includes a **trochophore** larva.

Unique Features. (i) Metameric segmentation. (ii) Haemoglobin in the plasma. (iii) Nephridia for excretion and osmoregulation. (iv) Setae.

Advancement over Roundworms. (i) Metameric segmentation. (ii) Circular and longitudinal muscles are present in both body wall and the wall of the alimentary canal. (iii) True coelom. (iv) Blood vascular system contains red blood.

Classification. On the basis of number and presence or absence of setae phylum Annelida is divided into five classes.

Class 1. Polychaeta (Gk. *polys*– many + *chaete* = hair). They have well developed **parapodia** with numerous **setae**. The development is indirect, undergoing metamorphosis with a free swimming **trochophore** larva. **Examples :** *Nereis*, *Aphrodite* (Sea mouse) *Polynoe* (Scaleworm), *Chaetopterus* (Paddle worm), *Sabella* (Peacock worm), *Arenicola* (Lug worm), *Amphitrite, Terebella* and *Serpula* (Fan worm). Both *Polynoe* and *Chaetopterus* are bioluminescents. *Arenicola, Amphitrite, Terebella* and *Serpula* have gills.

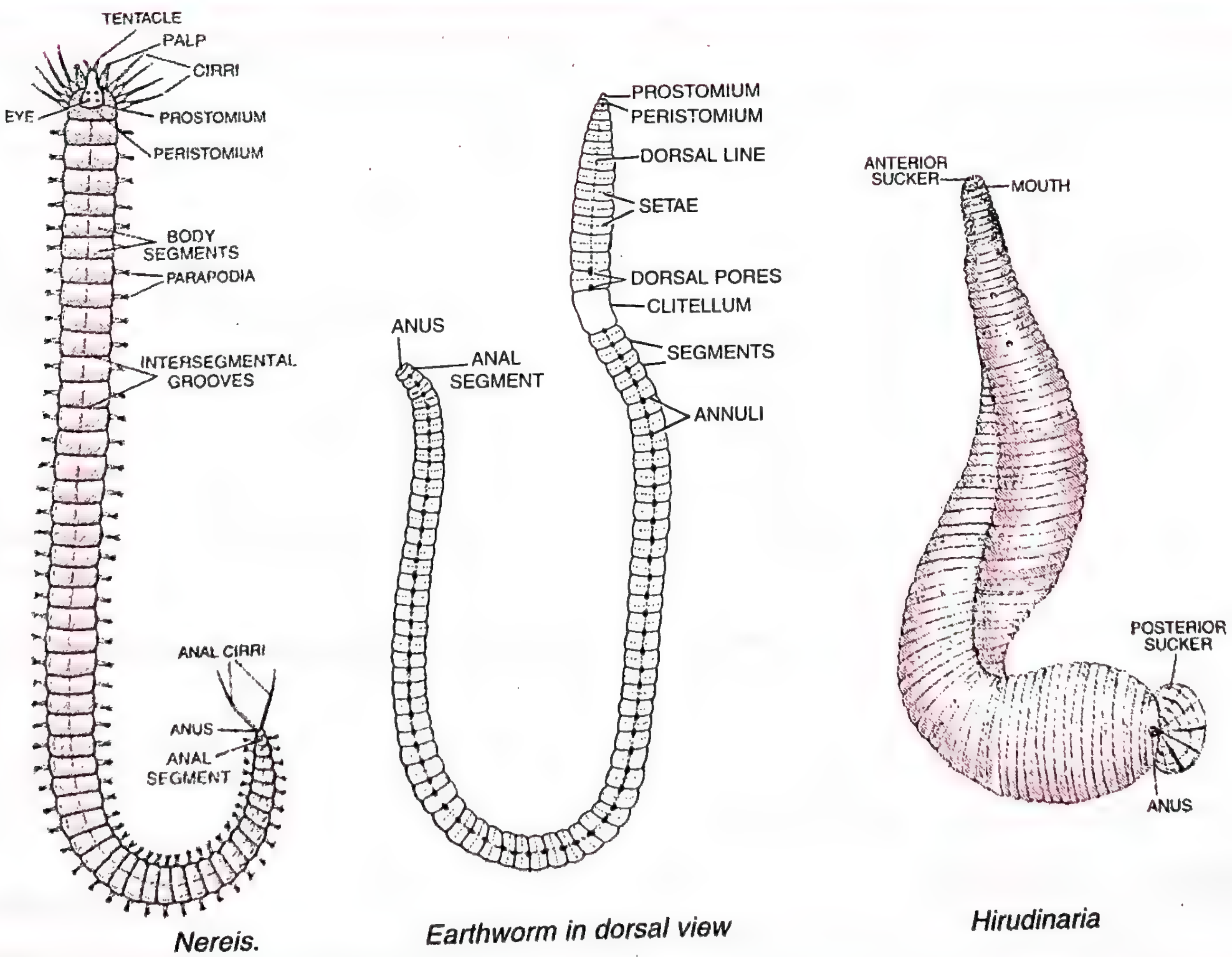


Fig. 4.23. Some Annelids.

Class 2. Oligochaeta (Gk. *Oligos*– few + *chaete* = hair). The body has few setae. There is no metamorphosis, *e.g.*, *Pheretima*, (Indian Earthworm), *Lumbricus*, (European Earthworm) *Tubifex*, *Magascolex* (common earthworm of South India).

Class 3. Hirudinea (L. *hirudo*– leech). They are ectoparasitic leeches. There are no parapodia or setae. Beneath the muscular layer of the body wall and surrounding the alimentary canal is found **botryoidal tissue** (peculiar connective tissue). Leeches have haemocoelomic system. **Examples :** *Hirudinaria* (Blood sucking leech), *Pontobdella, Hirudo, Acanthobdella.*

Class 4. Archiannelida. External segmentation is faint but internal segmentation is by septa and is complete. Examples *Polygordius, Dinophilus.*

Class 5. Echiurida. These annelids are without external and internal segmentation. Setae are rare. Examples *Bonellia, Echiurus.*

Neanthes (= ***Nereis***). It is commonly called **clam worm** or **sand worm** or **rag worm** which is found on the sea shore in tubular burrows. Nereis is unisexual and its reproductive phase is called ***Heteronereis***. Fertilization occurs in sea-water. During development, a trochophore larva is present. Except the peristomium (first segment) and last anal segment, each segment bears laterally one pair of fleshy projections, the **parapodia**, used in swimming.

Pheretima **(Earthworm).** It has been described in detail in Chapter 7A "Structural Organization of Animals".

***Hirudinaria granulosa*— The cattle leech.** It is an ectoparasite on cattle. *Hirudinaria* feeds on blood and hence called **sanguivorous**. The saliva of the leech contains an anticoagulant, called **hirudin** which prevents clotting of blood during blood meal. It is hermaphrodite, but cross-fertilization occurs. It is important to note that the segments 9, 10, 11 develop a *temporary clitellum* during breeding season. The leech bears two **suckers** : anterior and posterior. There are present **five pairs** of **eyes** on the dorsal surface. Some leeches are used as fish bait. Some leeches are used as surgical agents specially for curing diseases such as piles, baldness, etc, which is not correct.

ADDITIONAL INFORMATION

- *Bonellia viridis*. In this marine annelid, sexual dimorphism is very remarkable. Female is about 5 cm. Male is about 0.5mm. Male lives in the female's body.
- **Tubifex (= Blood worm)**. It is a bright red coloured worm which feeds on the organic matter found in sewage. Its blood contains haemoglobin. Presence of Tubifex indicates sewage contamination.
- In *Pontobdella*, the female shows parental care which guards the eggs for hatching.
- **Chaetopterus** (Paddle worm) It is highly **phosphorescent** and emits blue-green light. Reproduction is usually asexual (by transverse fission). The whole body can be regenerated from a single segment.

Phylum Arthropoda— the Animals with jointed feet or appendages

(Gk. *Arthron*– joint; *podos*– foot)

Von Seibold (1845) proposed the term **Arthropoda** and established it as phylum. The phylum Arthropoda includes the *largest number of animals* with 900,000 species. Thus this is the **largest phylum** of kingdom Animalia.

General Characters

1. **Habitat.** They occur on land, in the soil, in sea water, in fresh water and in the bodies of animals and plants as parasites.

2. **Body Form.** It varies considerably. They have jointed legs. The body is segmented externally. The body consists of **head, thorax** and **abdomen.**

3. **Body wall.** The body is covered with a thick, tough and non-living chitinous **cuticle**, which forms the **exoskeleton.**

4. **Body cavity.** The true coelom is greatly reduced in adults, and is only represented by the cavities of the reproductive and excretory organs. The body cavity is a **haemocoel** *i.e.*, cavity filled with blood.

5. **Digestive tract.** It is complete. The alimentary canal consists of **stomodaeum** (fore gut), **mesenteron** (mid gut) and **proctodaeum** (hind gut).

6. **Blood vascular system.** It is of **open type** *i.e.*, blood does not flow in definite vessels. There are present irregular spaces, known as **lacunae** or **sinuses**, filled with blood.

7. **Respiratory organs.** These are **gills** or **book gills** in aquatic forms and **tracheae** or **book-lungs** in terresterial forms.

8. **Excretory organs.** These are either **green glands** or **Malpighian tubules.** In some forms **coxal glands** are excretory organs.

9. **Nervous system.** The annelidian type of nervous system is present, *i.e.*, it consists of a nerve ring and a solid double ventral nerve cord with ganglia.

10. **Sense organs.** Sensory organs like antennae and eyes are present. In many arthropods, **compound eyes** are present, in which **mosaic vision** is developed. Some forms also have **statocysts** (balancing organs).

11. **No cilia.** An important feature of the arthropods is the complete absence of cilia.

12. **Muscles.** The muscles are generally striped, which are capable of rapid action. Unstriped muscles are also found.

13. **Endocrine glands.** Endocrine glands are present which secrete **hormones.** Some arthropods particularly insects excrete **pheromones.** The latter are chemicals which communicate message. Some pheromones act as sex attractants.

14. **Sexes.** Sexes are separate (dioecious) and the **sexual dimorphism** is observed in many forms.

15. **Development.** Fertilization is usually internal. They are mostly oviparous. Development may be direct or indirect. In indirect development there is **metamorphosis.**

16. **Parental care.** It is often seen in many arthropods.

17. **Parthenogenesis.** Development of an egg (ovum) into a complete individual without fertilization by a sperm, is called parthenogensis. Male honey bees (drones) are formed by parthenogenesis.

Examples : Economically important insects — *Apis* (Honey bee), *Bombyx* (Silk worm), *Laccifer* (Lac insect).

Vectors — *Anopheles, Culex* and *Aedes* (all the three are mosquitoes). Gregarious pest — *Locusta* (Locust). Living fossil — *Limulus* (King crab).

Trilobites (Fig. 4.24) are fossil arthropods which are over 600 million years old.

Unique Features. (i) Jointed appendages. (ii) Thick exoskeleton. (iii) Compound eyes. (iv) Haemocoel. (v) Antennary

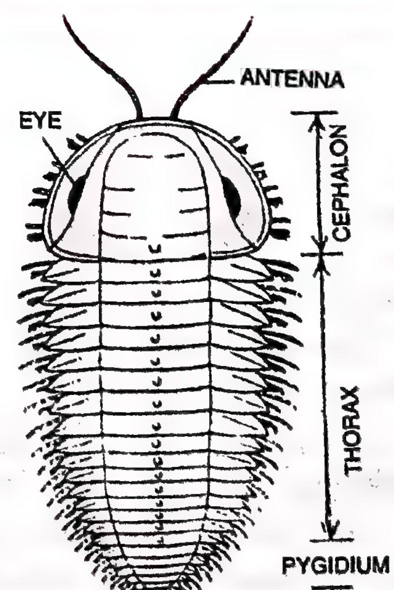


Fig. 4.24. Dorsal side of a *Trilobite.*

glands, Malpighian tubules and coxal glands for excretion and osmoregulation. (vi) Tracheae, gills, book gills, and booklungs as respiratory organs. (vii) Pheromones.

Advancement over Annelids. (i) Distinct head. (ii) Well developed exoskeleton. (iii) Jointed appendages for different functions. (iv) Striped muscles. (v) Endocrine glands and pheromones. (vi) Special respiratory organs such as tracheae, book lungs. (vii) Compound eyes.

Classification. On the basis of body divisions and presence or absence of certain appendages, the phylum Arthopoda is divided into seven classes.

Class 1. Crustacea. The body is divisible into **cephalothorax** (head + thorax) and **abdomen**. Dorsally, the cephalothorax is covered by a thick exoskeletal **carapace.** There are present two pairs of antennae and a pair of stalked compound eyes. **Examples :** *Palaemon*, (Prawn), *Astacus* (Cray fish), *Palinurus* (Lobster), *Cancer* (Crab), *Lucifer* (shrimp) *Eupagarus* (Hermit Crab), *Lepus* (Goose barnacle), *Balanus* (Acorn barnacle), *Sacculina* (a parasite on crab), *Oniscus* (Wood louse— terrestrial), *Squilla*, *Daphnia* (Water flea), Cyclops*.

Class 2. Chilopoda*[1]. Body is divisible into head and trunk. Each trunk segment bears a pair of legs. The first pair of legs are modified into **poison claws.** There is a single pair of antennae. **Example :** *Scolopendra* (centipede).

Class 3. Diplopoda*[2]. Body is divisible into head, thorax and abdomen. There is a single pair of antennae. Except first thoracic segment, (it does not have legs) each thoracic segment bears a pair of legs, however, each abdominal segment has two pairs of legs. **Example :** *Julus* (millipede).

Class 4. Insecta (Hexapoda). Body is divisible into head, thorax and abdomen. There is a pair of antennae, and a pair of compound eyes. The thorax consists of three segments with three pairs of legs and usually two pairs of wings. **Uric acid** is the chief excretory waste. **Examples :** silver fish, cockroach, bedbug, locust, termites, butterflies, rat flea, beetle, wasp, aphid, silk moth, etc.

Class 5. Arachnida. The body is usually divisible into cephalothorax and abdomen. The cephalothorax bears simple eyes and six pairs of appendages (one pair of **chelicerae**, one pair of **pedipalpi** and four pairs of legs). Antennae are absent. Respiratory organs are **book lungs** or tracheae or both. **Examples :** scorpion, spider, tick, mite.

Class 6. Onychophora. Example *Peripatus*.

Class 7. Merostomata. Example *Limulus*.

***Palaemon* (Prawn)**. Gills are the chief respiratory organs. The body is divisible into cephalothorax and abdomen. The cephalothorax bears 13 pairs of appendages. The abdomen has 6 pairs of appendages. The appendages are useful in feeding, swimming, balancing etc. The posterior end of abdomen forms a conical **telson**. Prawn is edible.

***Cancer* (Crab)**. Five pairs of thoracic legs are present in which first pair of legs forms enormous chelipedes.

***Peripatus* (The walking worm)**. It has characters of phylum Annelida and phylum Arthropoda. Hence it is a "**connecting link**" between Annelida and Arthropoda.

Annelidian characters. (i) Long, Worm-like body. (ii) Segmentally arranged nephridia.

Arthropod characters. (i) Antennae on the head. (ii) Tracheae for gas exchange.

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*It possesses a single median eye. It is named after one eyed giant Cyclops of Greek mythology.

1 & 2 *Chilopoda and Diplopoda were earlier included in a single class Myriapoda.

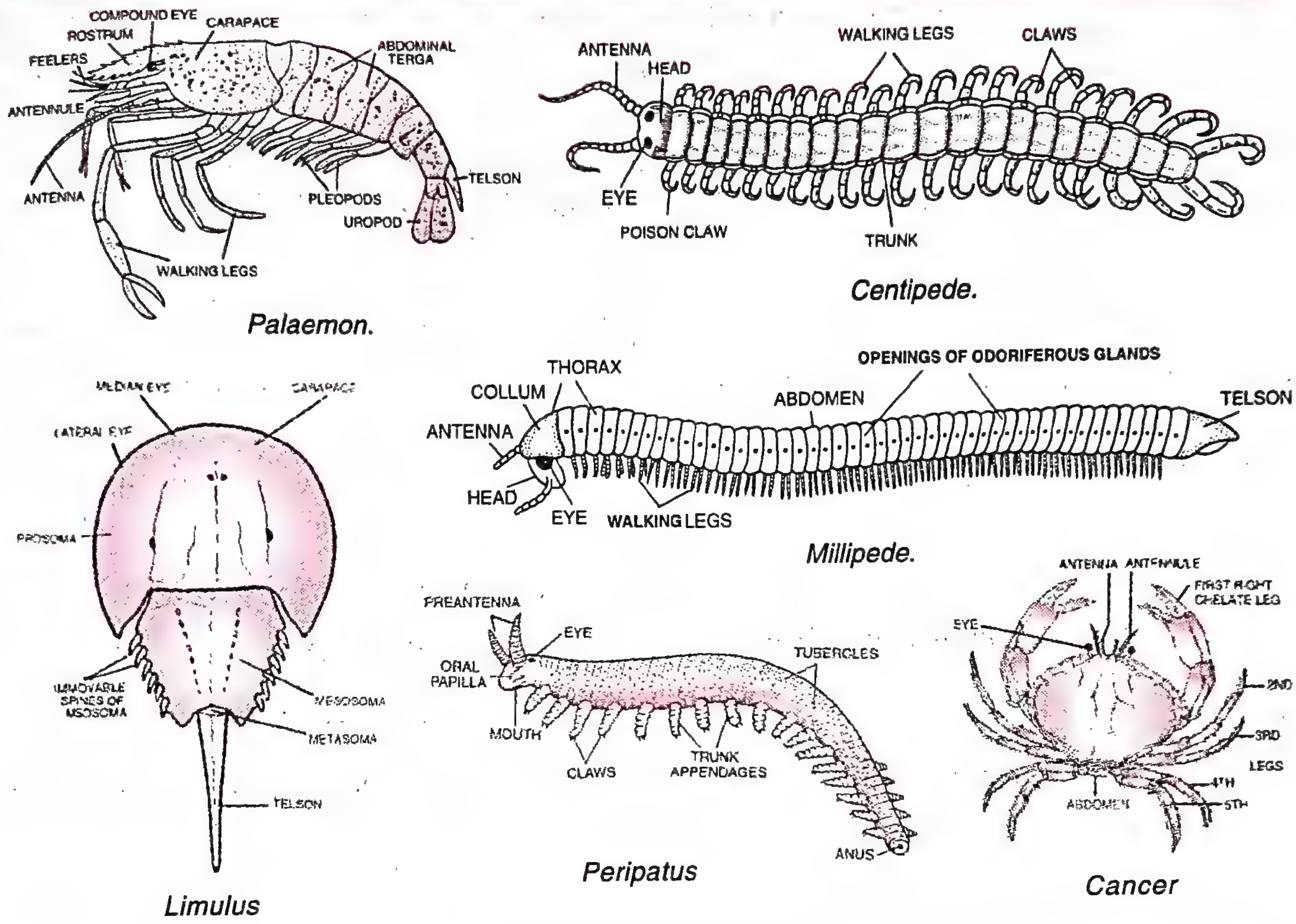


Fig. 4.25. Some Arthropods

***Limulus* (The king Crab or Horse-shoe crab).** The king crab continues to remain unchanged for the past about 190 million years. It is, therefore, also called "**living fossil**". Excretion takes place through four pairs of **coxal glands**. Respiratory organs are **book gills**.

External Characters of a Typical (generalised) Insect (Fig. 4.26)

The body of an insect is divisible into head, thorax and abdomen. There are six legs in an insect. Hence an insect is also called **hexapod**. Usually two pairs of wings are present. A pair of **anal cerci** generally arises from the posterior end of the abdomen. **Spiracles** are paired openings which lead into tracheae, the respiratory organs.

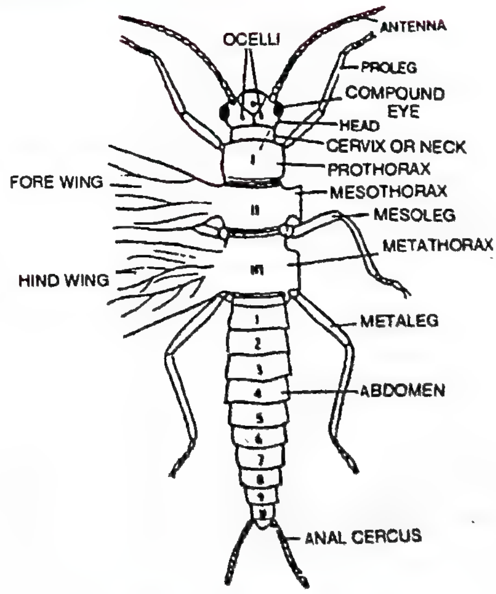


Fig. 4.26. A typical insect showing its various parts. Wings on the right side not shown while on the left side partly shown.

***Lepisma* (Silver fish).** It is common houseold pest, usually found in cool damp places, such as among old books, under picture frames, wall papers, clothes, etc. It is **wingless**. *Lepisma* does not undergo metamorphosis. The silver fish commonly feeds on starch, and cause considerable damage to books and clothes.

Mayflies. The mayflies are the *shortest-lived insects* and hardly survive a couple of days.

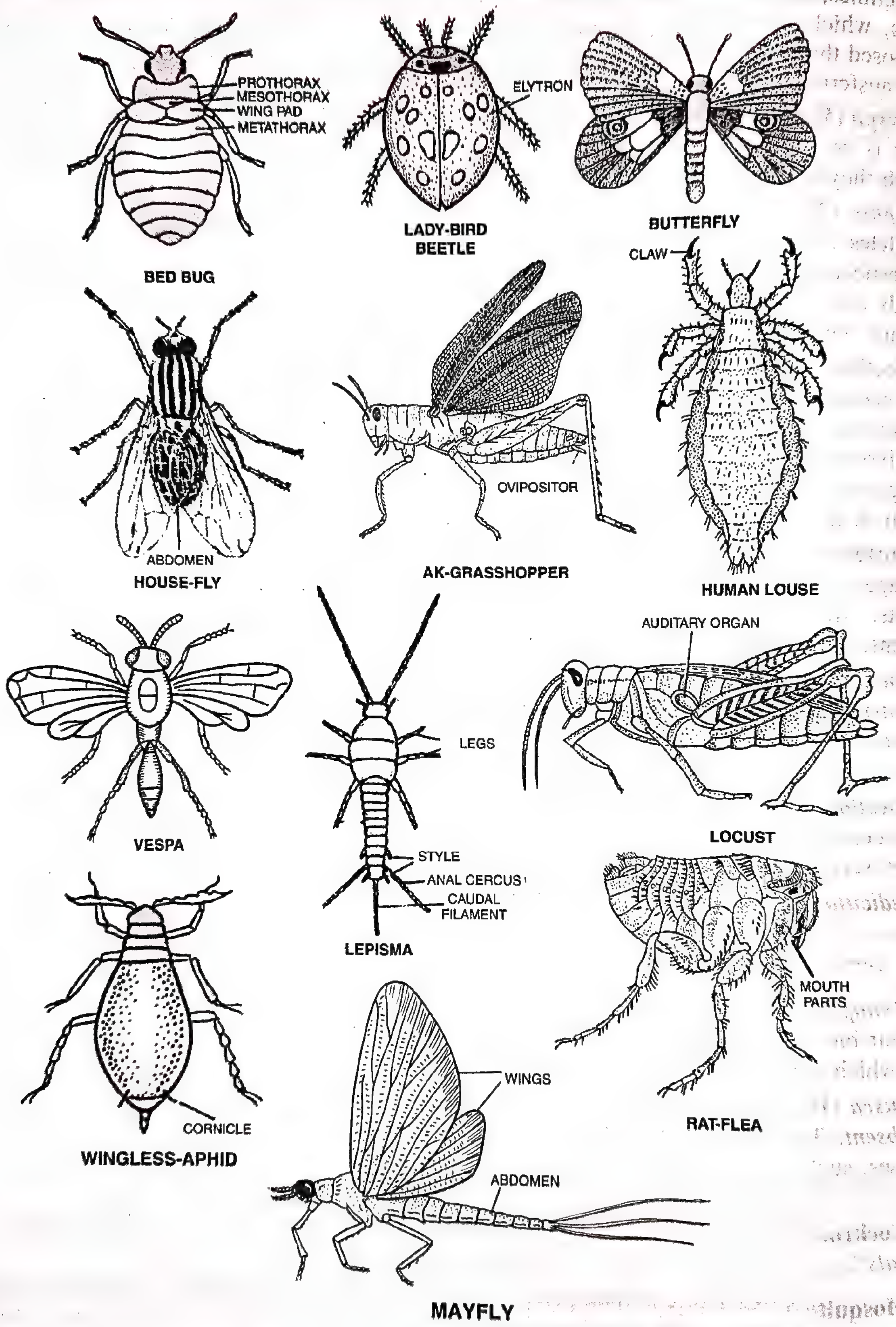


Fig. 4.27. Some insects.

***Cimex* (Bed Bug).** It lives as ectoparasite and sucks human blood so it is **sanguivorous.** Sometimes, they show **cannibalism.** The mesothorax is usually hidden by two small **wing pads,** which are the vestigial fore wings. The hind wings are completely absent. It is supposed that the germs of typhoid, plague, kala-azar, tuberculosis, relapsing fever, etc. can be transferred by them.

***Vespa* (Wasp).** They are colonial, polymorphic and social insects, living in the hives. The body is yellowish in colour. They are *trimorphic.* The workers have a powerful sting by which they can inject into the human body causing pain.

***Aphis* (The Aphid).** The aphid sucks plant sap. It excretes 'honey dew' through the **cornicles (honey dew tubes).** The 'honey dew', being sweet is eaten by ants. The ants domesticate the aphids for this purpose. Such aphids are called "ant cows". The female aphids are *viviparous* and reproduce by *parthenogenesis.* Aphids are serious pests. They damage the plants by sucking their sap.

Beetles. They are mostly pests of crops. The fore-wings are thickened, leathery, hard and opaque, which are called wing covers or **elytra.** They are not used for flight. The order *Coleoptera in which the beetles are placed, is the largest order in the animal kingdom.* Herbivorous beetles feed on vegetables, thus they spoil useful crops. They also spoil stored foodgrains. Some carnivorous beetles feed on aphids, the harmful insects, therefore, they are useful in this respect.

Butterflies. They are diurnal in habit. *Pieris* (**the cabbage butterfly**) lays eggs on cabbage leaves. The larvae are worm-like and called *caterpillars.* They are usually coloured insects. Most of the butterflies are quite destructive, as they feed on crops, orchards, gardens, etc. They are useful in cross pollination.

Locust. There are many locusts but *Schistocerca gregaria* (desert locust) and *Locusta migratria* (migratory locust) have been known from time immemorial. *They are the most destructive of all insects.* Locusts come to India from Pakistan. Locusts are serious plant pests.

***Poecilocerus pictus* (Ak-grasshopper).** Grasshopper is essentially a solitary insect. *Poecilocerus pictus* lives on Ak plants. It feeds on leafy vegetation. Therefore, it sometimes causes serious damage to the crops.

***Pediculus* (Human louse).** *Pediculus humanus* is an ectoparasite of human beings and feeds on their blood. Eyes are poorly developed. Wings are absent. They suck the blood and carry germs of **typhus fever.**

***Xenopsylla* (Rat flea).** *Xenopsylla cheopis* is an ectoparasite of rats and men and feeds on their blood. Wings are absent. *Xenopsylla cheopis* transmits *Bacillus pestis* from rat to man which causes **bubonic plague.**

***Musca* (House Fly).** They are **saprophagous** in diet, *i.e.*, taking fluid only. *Mandibles are absent.* They are very harmful insects because they spread the germs of some dangerous diseases, such as cholera, typhoid, paratyphoid, anthrax, diarrhoea, dysentery, tuberculosis, etc.

Cockroach. *It has been described in detail in Chapter 7A– "Structural Organisation of Animals".*

Mosquitoes (Fig. 4.28). The males generally feed on plants juices, while the females feed on blood. Its saliva contains **anticoagulant.** There are present piercing and sucking type of mouth parts. *Mandibles are absent in male mosquito.* The metathorax bears two club-

shaped processes known as **halteres** or **balancers**. The **pedicel** (second segment) of the antenna contains **Johnston's organ** which perceives sound vibrations like an auditory organ (hearing organ). *Plasmodium* (Malarial Parasite) which causes **malaria fever** is transmitted by the female anopheles. *Filaria* which causes **filariasis** is transmitted by *Culex*. **Encephalitis** is caused by a virus in man, which results in high fever, headache, drowsiness and inflammation of the brain. This virus is also transmitted by some species of *Culex*. ***Aedes*** mosquito transmits virus of **Dengu fever, Yellow fever** and **Chikungunya.**

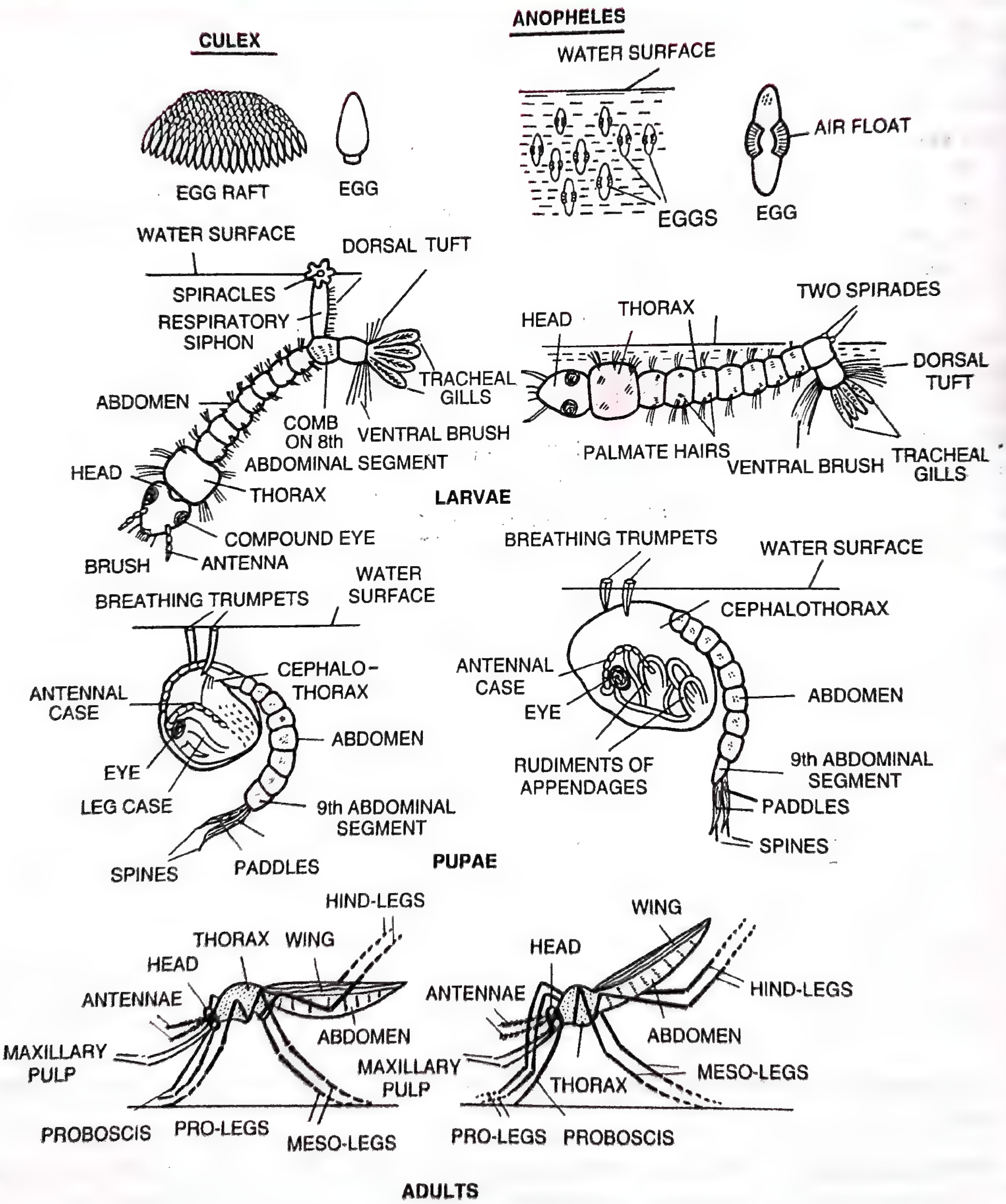


Fig. 4.28. Life history of *Culex* and *Anopheles*.

Differences between the life history of Culex and Anopheles

Culex	*Anopheles*
Egg	
1. Eggs are cigar shaped and laid vertically on the surface of dirty water in clusters forming **rafts**.	1. Eggs are boat shaped and laid horizontally and singly on the surface of clear water.
2. The eggs do no have lateral air floats.	2. Each egg has two lateral air floats.
3. Female Culex lays 150 to 300 eggs at a time.	3. Female Anopheles lays 40–100 eggs at a time.
Larva	
4. Larva is bottom feeder.	4. Larva is surface feeder.
5. At rest, larve hangs obliquely from the surface of the water.	5. At rest, the larva lives parallel to the surface of water.
6. Respiratory siphon is long.	6. Respiratory siphon is absent.
Pupa	
7. Breathing trumpets are long.	7. Breathing trumpets are short.
8. Greyish in colour.	8. Greenish in colour.
9. Each paddle bears a single long spine.	9. Each paddle bears two unequal spines.
Adult	
10. Wings are without dark spots.	10. Wings have dark spots.
11. At rest, the body lies more or less parallel to the surface.	11. At rest, body lies at an angle of 45° to the surface.

Termites (White ants). Termites are colonial, polymorphic and social insects. In the colony, mostly two forms are present; fertile caste and sterile caste. Fertile castes include the fertile males and females. Sterile castes include both males and females but are without wings and their reproductive organs are vestigial. Sterile castes include workers, nasutes and soldiers. During the breeding season, the winged male and female fly together which is

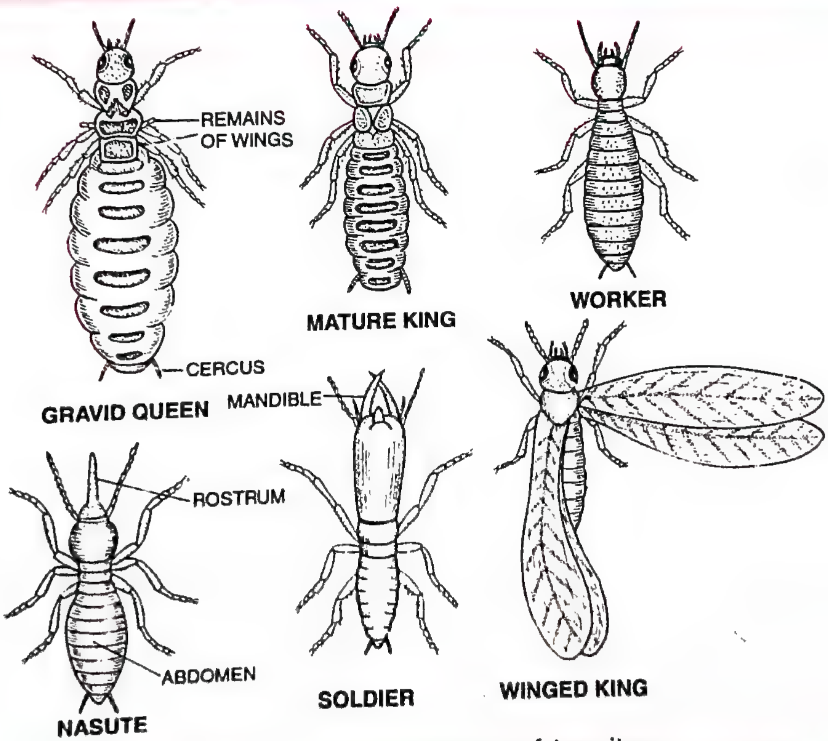


Fig. 4.29. Different castes of termites.

known as **nuptial flight** during which copulation occurs. (i) **Queen.** She lays eggs. (ii) **King.** The king fertilizes the queen. (iii) **Workers.** The workers construct and repair the nest **(termitarium),** collect the food, look after the eggs and feed the nymph and other castes. (iv) **Nasutes.** They have at the tip of head opening of the frontal gland. The secretion of this gland is sticky in nature and used in the warfare during which it is inflected upon their enemies. This secretion is also used to dissolve hard substances, which workers face during nest formation. (v) **Soldiers.** They defend the colony.

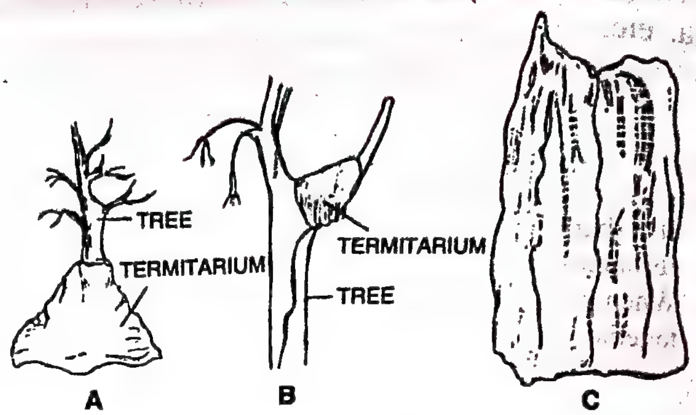


Fig. 4.30. Termite nests. (A) A Termitarium from South Africa (about 90 cm high). (B) A termitarium from Panama. (C) A termitarium from Australia (about 375 cm high).

The main food constituent is cellulose, which they obtain from wood or wood work. They are able to digest cellulose with the help of certain flagellates such as ***Trichonympha*** that live in their intestine.

The exchange of food between one insect and the other is called **tropholaxis** which is common in termites.

Ants. Like termites they are social, colonial and polymorphic insects. Tropholaxis is common in the ants. Generally male and female go on a nuptial flight. After mating, the males usually die. The mated females shed their wings and lay eggs in the nests. The main castes of ants are the following. (i) **Queens**. They are fertile females. They may live up to 15 years in some species. (ii) **Kings**. They are fertile male ants. (iii) **Workers**. Actually they are sterile, wingless females, which are smallest in the nest. The workers take over the feeding of the queen and larvae. They also store the food and build the nests. (iv) **Soldiers**. They are modified workers bearing large head and powerful serrated mandibles. They protect nest from the enemies.

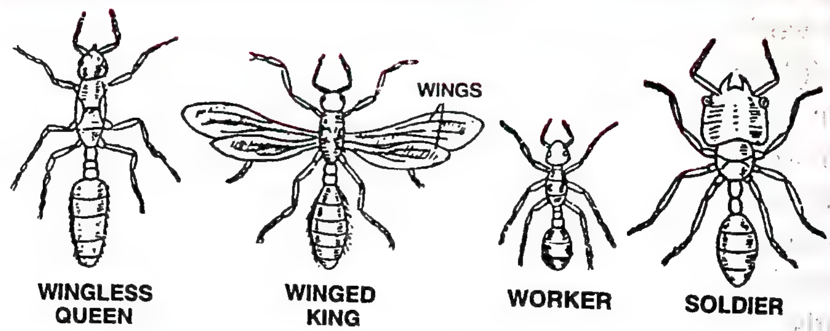


Fig. 4.31. Different castes of ants.

Ants destroy in bulk seeds and grains from fields and godowns. Their useful activities are helpful in pollination, act as scavengers by disposing dead bodies of animals, increase the fertility of soil by burrowing.

Silk Moth (*Bombyx mori*). It is also called mulberry silk moth, which never occurs in the wild state and is a completely domesticated moth. It is called "Resham- Ka- Kira" in Hindi. It is extensively cultivated all over the world. In India, Kashmir, Mysore and Coimbatore are the main silk producing centres. The adults do not feed and survive for two to three days only. They fly very rarely. The male dies soon after copulation and female after laying eggs. The silk is obtained by killing the pupa inside the hot water . Then, the silk thread is wound. About 1000 metres of silk thread can be obtained from a single coccon and about one pound of silk can be obtained from 25000 coccons. Rearing of silk moth for obtaining

raw silk is called **sericulture**. It is done on large scale in China, Japan, Italy, France, Brazil, India, etc.

Differences between Butterfly and Moth	
Butterfly	*Moth*
1. It is diurnal (active in day). 2. Its antennae are knobbed distally. 3. When it is at rest, it keeps the wings held together vertically on its back.	1. It is nocturnal (active at night). 2. Its antennae taper distally. 3. When it is at rest it keeps the wings held out horizontally.

Apis (Honey Bee). Species of Honey bee are (1) *Apis mellifera* — Italian bee, (2) *Apis dorsata*— Rock bee - largest, (3) *Apis indica*— Indian bee, (4) *Apis florea*— Little bee - smallest. Most common Indian honey bee in wild state is *Apis indica*, however in domestic state, the most common Indian honey bee is *Apis mellifera* (Italian honey bee). Honey bees are colonial, social and polymorphic insects. *Unfertilized eggs develop into drones (males) by parthenogenesis*. Fertilized eggs develop into queens or workers. Three types of individuals (castes) are found in the colony of honey bees; (i) **Queen** is a fertile female. (ii) **Drones** are males. Life span of a drone is 1–2 months. (iii) **Workers** are sterile females and perform various duties of the colony. The queens are fed by the workers. The abdomen contains the wax glands and the sting. The worker bees of a hive fall into three major castes.

(a) **Scavenger** or **Sanitary bees**. For the first three days each worker bee acts a scavenger. (b) **House or Nurse bees.** From the fourth day onwards, each worker bee feeds like a foster mother, with a mixture of honey and pollen. From the seventh day, the **maxillary glands** of a worker bee secrete **"royal jelly"** to feed young larvae, the queen and those older larvae which are destinated to develop into future queens. From the twelfth to the eighteenth day, each worker bee develops wax glands. Wax is secreted in the form of thin scales. (c) **Foraging** or **Field Bees**. When a worker bee is about 15 days old, it explore new sources of nectar and pollen and collect these and water. These bees are also called **scout bees. Ernest Spytzner** (1788) was the first to draw attention to the fact that bees

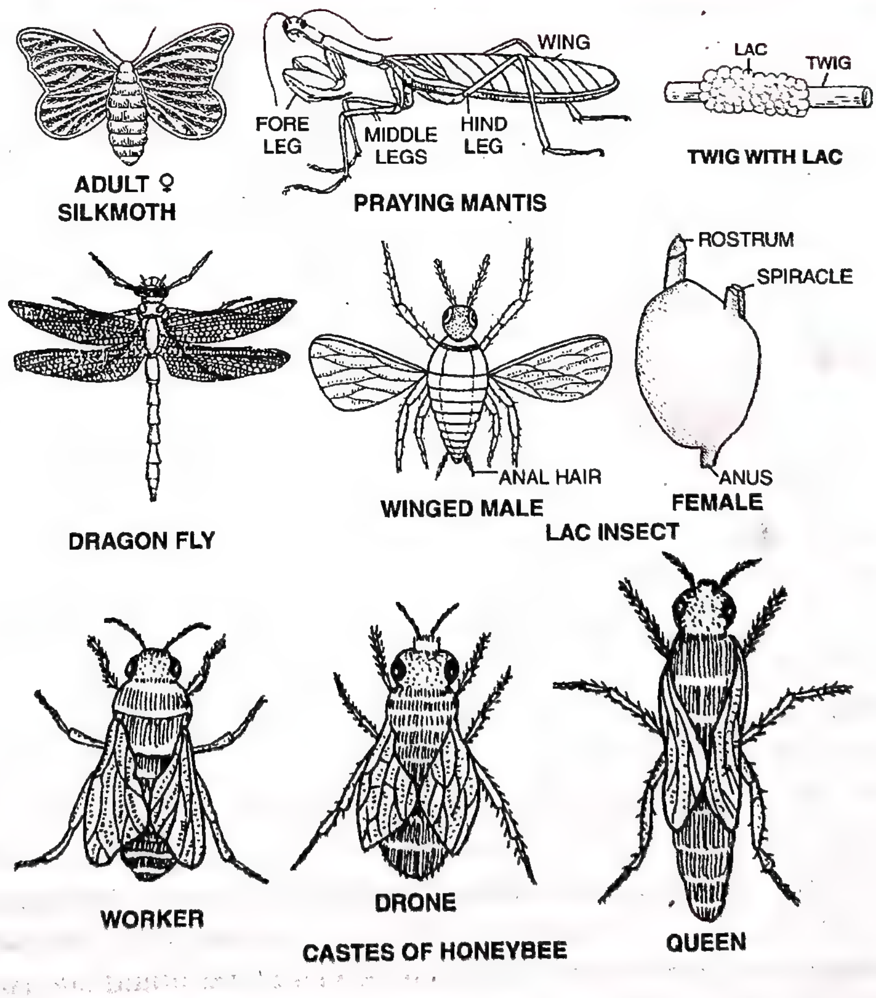


Fig. 4.32. Some useful Insects.

communicate by means of definite movements now called "**bee dances**". **Prof Karl von Frisch** decoded the language of "bee dances" and got **Nobel Prize** in medicine or physiology for it in 1973. He discovered that scout bees perform two types of dances for communication. (i) **Round dance** is performed when a newly discovered food source is close (less than 75 metres) to the hive (ii) **Tail wagging dance** is performed for long distance sources. Life-span of a worker honey bee is 3-4 months.

Economic importance : (i) Honey bees provide honey. Honey is a natural valuable tonic for human body. It contains enzymes, vitamins, monosachharide sugars mainly glucose and fructose, pigments, ash, moisture, minerals and so on. Honey has neutral *p*H. Honey also acts as antiseptic. (ii) Bee wax is used in making candles, polishes, toilet goods, cosmetics, electric goods, carbon paper, etc. (iii) Honey bees help in the pollination of flowers of fruit plants and seed crops. (iv) Their sting is poisonous and sometimes fatal to man when they attack in large numbers.

Rearing of honey bees to obtain honey and bee wax is called **apiculture**. A place where bees are kept is known as **apiary**. A person who keeps bees is called **apiarist**.

***Laccifer* (*Tachardia*) *lacca*— Lac Insect.** It is found in thick forest in India, Myanmar (Burma), Ceylon (Sri Lanka), Thailand, Philippines, Formosa and East Indies. The females are degenerate individuals, without wings, legs and eyes. The body of the female is soft, ovoid and without segmentation. It has at the anterior end a 2-jointed rostrum and 2-short processes bearing a pair of spiracles. Male has a segmented body divisible into head, thorax and abdomen. The abdomen bears at its end a pair of long **anal hair**. There is sexual reproduction. The females can also reproduce parthenogenetically. The males are active and females are motionless.

During unfavourable season, the females secrete lac to form protective nest for egg-laying upon branches of *Peepal, Dhak, Bargad* and other trees. **Nymphs**, not larvae, hatch-out from the eggs. Lac is scraped from the surface of trees, crushed and sieved to produce **lac dust**. It is used in the manufacture of shellac, varnish, polish, buttons, bangles, toys and some electrical items. A dye is prepared from dead and dried bodies of the females. This dye is used by women folk of our country for *mahavar*. India is the major lac producing country.

***Sympetrum* (Dragon Fly).** The dragon flies are mostly found in the vicinity of water. They are also called the "mosquito hawks" as their main diet is mosquitoes. Thus, they help in controlling malaria. The female lays eggs in the water. The **naiads** are stout, and their rectum is elongated to form a rectal respiratory chamber in which the gaseous exchange takes place. In the rectal chamber, the naiad draws water and then expels out. This is an unusual structure, which occurs in naiads of dragon fly only.

***Mantis* (Praying mantis).** Praying mantis is usually found on the leafy vegetables, where it feeds on other insects which it captures by means of their prehensile fore-legs. Cannibalism is very common in these insects. Praying mantis destroys certain harmful insects, so it is a useful insect.

***Palamneus* (Scorpion).** It is **viviparous**. The body is divisible into (i) anterior the *prosoma* and (ii) posterior the *opisthosoma*.

(i) **Prosoma.** It is unsegmented and covered by a **carapace**. The latter bears a pair of large median eyes and two groups of smaller lateral simple eyes, each group comprises three eyes. Ventrally the prosoma has a sternal plate and six pairs of appendages, *i.e.*, one pair of small **chelicerae**, one pair of **pedipalpi** and four pairs of **walking legs**.

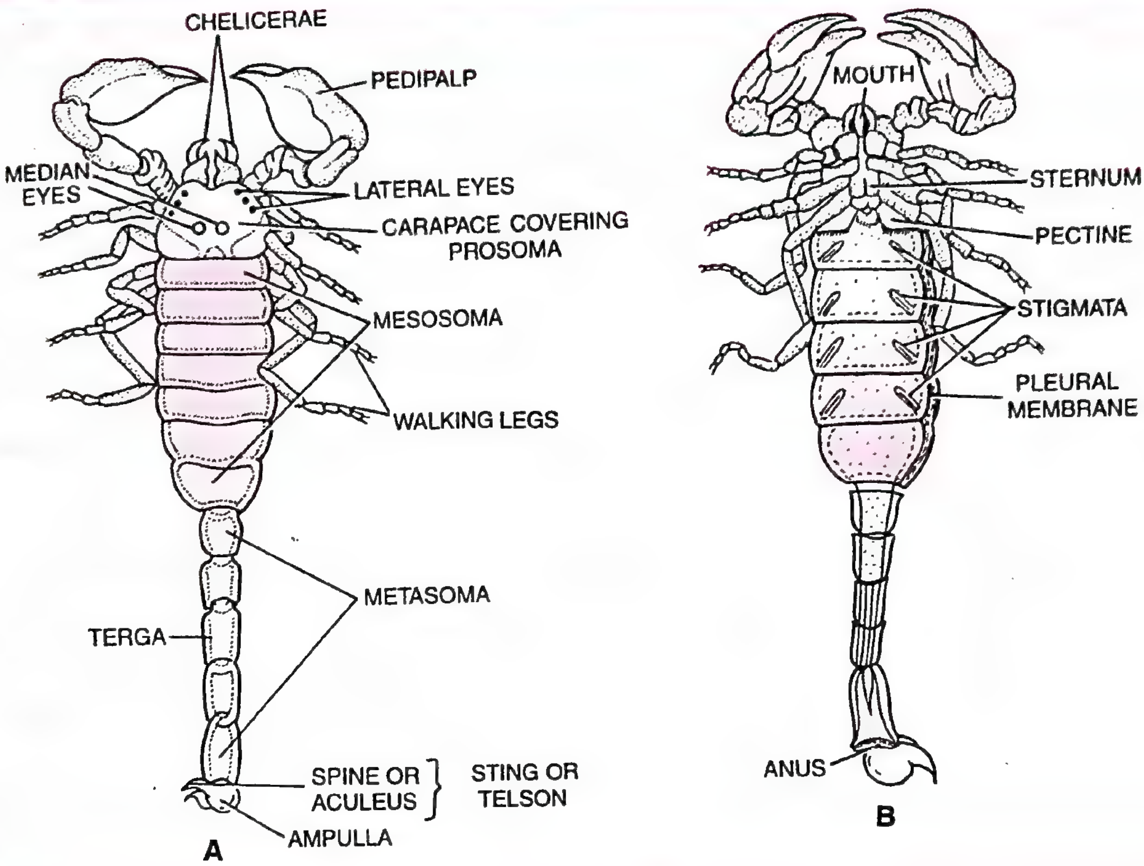


Fig. 4.33. Scorpion. A, Dorsal view; B, Ventral view.

(ii) **Opisthosoma.** It is differentiated into anterior mesosoma and posterior metasoma. (a) **Mesosoma.** It is made of seven segments. The sternum of the second segment bears a pair of comb-like sensory appendages, the **pectines.** The sternum of each of 3rd, 4th, 5th and 6th mesosomal segments bears a pair of oblique slit like openings the **stigmata**, which lead into respiratory organs, the **book lungs**. (b) **Metasoma.** Its posterior narrow part consists of five segments. The last segment bears the anus and a stinging apparatus or **telson**. The latter consists of a swollen base, the vesicle or **ampulla** and a curved and pointed spine, the **aculeus.** Inside the vesicle lies a pair of **poison glands**, the ducts of which open by a pair of minute apertures at the tip of the spine.

***Aranea* (Spider).** The body is divisible into an anterior cephalothorax and a posterior abdomen. The cephalothorax has six pairs of appendages (one pair of chelicerae, one pair of pedipalpi and four pairs of walking legs). The abdomen is unsegmented, rounded and without telson but has three pairs of spinnerets or spinning organs which produce threads for the construction of spider web. Book lungs and the tracheae are the respiratory organs. Excretory product of spider is guanine. Poisonous spider is *Lectodectus meactans*.

***Sarcoptes* (Mite).** *Sarcoptes scabiei* is a dangerous ectoparasite which attacks man, causing **scabies**, producing severe irritation. Anterior two pairs of legs are stronger. Posterior two pairs of legs are shorter and attached more ventrally and carry long bristles.

***Ixodes*. (Sheep tick).** The body is covered with leathery skin and is without segmentation. Four pairs of legs are segmented. The tarsus of first pair of legs has a sensory cup-shaped **Haller's organ**. Respiration is by spiracles and tracheae. It has blood sucking mouth parts. Its saliva contains an **anticoagulin** which prevents coagulation of blood. It feeds on the blood of sheep.

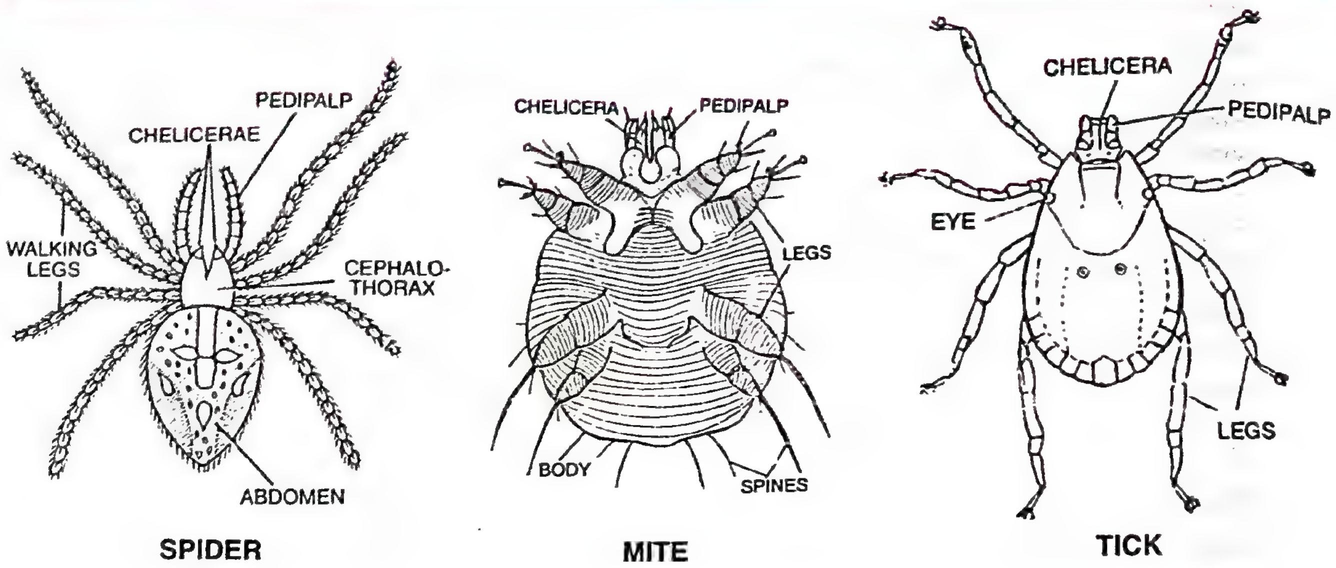


Fig. 4.34. Some Arachnids.

Differences between Insect and Spider

Insect	*Spider*
1. Body is divisible into head, thorax and abdomen.	1. Body is divisible into cephalothorax and abdomen.
2. It has compound eyes.	2. It has simple eyes.
3. Labrum, labium, hypopharynx, mandibles and maxillae are the mouth parts.	3. Chelicerae and pedipalpi are the mouth parts.
4. Wings are usually present.	4. Wings are absent.
5. Three pairs of legs are present.	5. Four pairs of legs are present.
6. Antennae are present.	6. Antennae are absent.
7. There are no spinnerets.	7. There are present 3 or 4 pairs of spinnerets which occur on abdomen for producing threads for construction of spider web.

ADDITIONAL INFORMATION

- **Cyclops.** Its head bears a **single median eye**. Mature female carries a pair of posterior egg sacs, filled with eggs. It means its female shows parental care.
- **Daphnia– The Water Flea.** There is **single compound eye.** Female carries eggs and embryos in a large brood pouch.
- Both *Cyclops* and *Daphnia* act as zooplankton which form important link in the food chain in water.
- **Carcinology.** (i) Study of Crustaceans (ii) Study of cancer.
- **Entomology.** Study of insects.
- **Entomophily.** Pollination by insects.
- **Luminescent Insects** *Photinus, Lampyris* and some other genera bear light producing organs upon their abdomen. These are, therefore, called **fireflies or glow worms.** Light is emitted at short intervals by both male and female individuals as a visual signal to attract each other for copulation.
- In India, Urban malaria is transmitted by *Anopheles stephensi*, however, rural vector in India is *Anopheles culicifacies*.
- Usually the larger an animal is, the longer it takes to grow up. One exception is the

17 year *Cicada* (an insect), which spends a very long time as a larva.

- In all insects the interval between two ecdysis (casting of skin) is known as the **stadium** and the form assumed by the young insect during a stadium is called an **instar**.
- Silk glands of the caterpillar of the silk moth are actually modified salivary glands.
- Spider webs are made of silk which is one of the strongest natural substance.
- Loudest insect is male *Cicada*. Sound can be heard upto 4 km. Its absence has given the silent valley of Kerala, its name.
- Monarch butterfly is poisonous.
- Honey bees are regarded the world's most advanced landmine detectors.
- **Blister beetle–Lytta.** This insect is obundantly found in France and Spain. A drug, called **Cantheridin** prepared from its blood, is widely use for healthy growth of hair.
- **Cochineal bug.** Its dead and dried body is used for preparing a dye called **cochineal**. This dye is used by our women folk for "alta" or "mahavar".
- *Aedes albopictus* is the scientific name of Asian tiger mosquito.
- *Sacculina* is a crustacean parasite on crab. A peculiarity of this parasite is that if it attacks a male, the crab will change its sex and turn into a female. If it is female crab the ovary gets degenerated and changes into juvenile type. These changes are called **parasite castration**.
- Oniscus (wood louse). It is a terrestrial crustacean found under stones, logs, bark etc., which is purely air breather.
- **Astacus** (Cray-fish). It is fresh water crustacean which is relished as food.
- **Phyllium** (Leaf Insect). Its wings are remarkable in having leaf-like colouration and venation. It is perfect example of **mimicry**.
- World Mosquito Day- August 20.
- **Four Major Groups of Insects.** The insects may be divided into four groups on the basis of their mode of development.

  1. **Insects without Metamorphosis (Ametabolous development).** Certain insects, such as silver fish, do not undergo metamorphosis. These insects are most primitive and wingless. There are present three stages in the life history; **egg, young** and **imago** (adult).

  2. **Insects with Gradual Metamorphosis (Paurometabolous development).** In this type of metamorphosis, the life history includes **egg, nymph** (young) and **imago** (Adult). The nymph resembles the adult in its mode of life but differs in structure, the young being without wings. Gradual metamorphosis occurs in cockroaches, grasshoppers, locusts, termites, stick insects, praying mantis, bed bug and lice.

  3. **Insects with Incomplete Metamorphosis (Hemimetabolous development).** In this type of metamorphosis, the life history includes **egg, naiad** (young) and **imago** (adult). The naiad differs from the adult in both mode of life and structure. Incomplete metamorphosis occurs in dragon flies and may flies.

  4. **Insects with Complete Metamorphosis (Holometabolous development).** In this type of metamorphosis the life history includes **egg, larva, pupa** and **imago** (adult). A larva differs from the adult in form, structure and mode of life. A pupa is an inactive stage. The latter is transformed into an adult by radical changes. Complete metamorphosis occurs in butterflies, moths, beetles, house flies, mosquitoes, fleas, honey bees, ants and wasps. The larva of butter flies and moths is called **caterpillar.** The larva of houseflies is known as **maggot**. The larva of beetles is termed **grub** and the larva of mosquito is called **wriggler**.

- Types of Mouthparts in Insects. Generally mouth parts of an insect are one labrum, one labium, one hypopharynx, two mandibles and two maxillae. Following types of mouth parts are found in insects.

  1. **Biting and Chewing type.** Examples: Grass-hoppers, cockroaches and crickets.
  2. **Piercing and Sucking type.** Examples: Mosquitoes, bedbugs.
  3. **Chewing and Lapping type.** Lap means to drink by scooping with tongue and lapper is that which laps liquid. Example: Honey bees.
  4. **Sponging type.** Example: House fly.
  5. **Siphoning type.** Examples: Butter flies and moths.

Common Human Diseases Transmitted by Insects

	Insect Vectors	Diseases Transmitted
1.	**Flies**	
	(i) Housefly	Typhoid, Diarrhoea, Dysentery, Cholera, Tuberculosis, Trachoma, Conjunctivitis, Amoebiasis, Poliomyelitis (Polio).
	(ii) Sandfly	Kala-azar, Oriental Sore
	(iii) Tse tse Fly	African Trypanosomiasis (African sleeping sickness)
2.	**Rat flea**	Bubonic Plague.
3.	**Mosquitoes**	
	(i) *Anopheles*	Malaria
	(ii) *Culex*	Filariasis (Elephantiasis), Encephalitis
	(iii) *Aedes*	Yellow Fever, Dengue Fever, Chikungunya and Encephalitis.
4.	**Lice**	Trench Fever, Relapsing Fever, Epidemic Typhus fever.
5.	**Triatomid Bugs**	Chagas' Disease (South American Trypanosomiasis— South American Sleeping Sickness)

Phylum Mollusca— The Soft Bodied Animals (L. *Molluscs*– soft)

Johnston gave the term mollusca. Phylum Mollusca is the **second largest** *animal phylum* which includes over 60,000 species.

General Characters

1. **Habitat**. They are mostly marine. Many, however, occur in fresh water and some even in damp soil.

2. **Body Form**. The body of molluscs is unsegmented with a distinct **head, muscular foot** and **visceral hump**. *Neopilina* is a segmented mollusc.

3. **Symmetry**. They usually show bilateral symmetry. In some molluscs like *Pila,* due to **torsion** (twisting) during growth, the adults become asymmetrical.

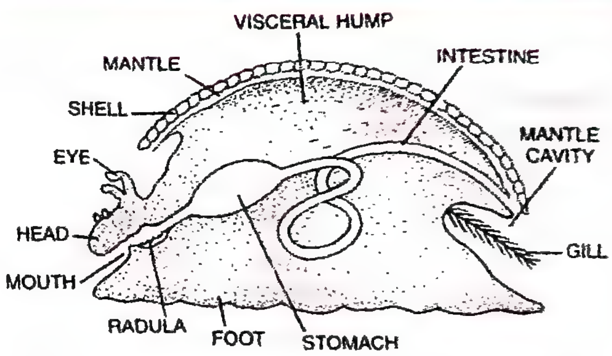


Fig. 4.35. Body plan of molluscs (Hypothetical).

4. **Shell.** Shell is secreted by mantle. It is made up of calcium carbonate. Shell may be external (*e.g.*, most of molluscs), internal (*e.g.*, slug, cuttle fish, squid) or absent (*e.g.*, *Octopus*).

5. **Mantle (Pallium).** It is a thin, fleshy fold of dorsal body wall more or less covering the body. It encloses a space, which is called **mantle cavity** (= pallial cavity).

6. **Body wall.** Single layered epidermis is usually ciliated. Muscles are unstriped and occur in bundles.

7. **Body cavity.** Coelom is greatly reduced. It is restricted to pericardial cavity (space around the heart), and to small spaces within kidneys and gonads (testes and ovaries). Spaces amongst the viscera (soft organs) contain blood and form **haemocoel.**

8. **Digestive tract.** It is complete.

9. **Blood vascular system**. It is open type. It includes dorsal heart, arteries that open into sinuses (spaces) and veins. Blood is usually blue due to the presence of a *copper-containing blue respiratory pigment* called **haemocyanin**. Among the molluscs, cuttle fish are exceptional in having closed blood vascular system.

10. **Respiratory organs.** These are gills **(ctenidia)**, mantle and **pulmonary sac** (in semi terrestrial form).

11. **Excretory organs.** Excretory organs are one or two pairs of sac- like kidneys. Gills are also excretory in function. Ammonia is the chief excretory matter.

12. **Nervous System.** The nervous system comprises paired **cerebral, pleural, pedal** and **visceral ganglia** joined by the nerve connectives and commissures. Connectives connect dissimilar ganglia, however, commissures connect similar ganglia.

13. **Sense Organs.** In many molluscs, eyes are present over stalks called **ommatophores. Statocysts** (balancing organs) may be present. **Osphradium** is present in some molluscs for testing chemical and physical nature of water.

14. **Sexes.** The sexes are generally separate but some are hermaphrodite.

15. **Development.** They are oviparous. The development is either direct or indirect (metamorphosis). When the development is indirect, it includes a characteristic larva, **veliger, trochophore** or **glochidium**. Asexual reproduction is absent.

Unique Features. (i) Mantle covers the body. (ii) Mantle may be surrounded by shell. (iii) Nervous system consists of cerebral, visceral, pleural and pedal ganglia.

Advancement over Annelids. (i) Shell is present in many individuals. (ii) In some forms, a lung is present for pulmonary respiration. (iii) Better developed sense organs such as eyes, statocysts and osphradia.

Classification. Phylum Mollusca is divided into six classes.

Class 1. Monoplacophora (Gk. *monas*– one, *plax*– plate, *pherein*– bearing). The shell is spoon or cup-shaped. They have the characters of both the phylum Annelida and phylum Mollusca. **Example :** *Neopilina*.

Class 2. Amphineura (Gk. *amphi*– both + two *neuron* = nerve). There is present a nonganglionated nerve ring around mouth with two pairs of interconnected nerve cord. **Examples :** *Chaetopleura (Chiton)*.

Class 3. Scaphopoda (Gk. *scapha*– boat, *podos*– foot). Shell is tubular and open at both ends. **Example :** *Dentalium* (Tusk shell).

Class 4. Gastropoda (Gk. *gaster*– belly, *podos*– foot). Shell is made up of one piece. The early embryo is symmetrical but during development the body twists showing **torsion** so that the body becomes asymmetrical. It includes the *largest number of molluscs e.g., Pila, Limax, Cypraea* (Cowrie), *Helix* (garden snail), *Aplysia* (sea hare), *Doris* (sea lemon), *Limnaea*, (pond snail), *Planorbis, Patella* (true limpet), *Turbinella* (Shankh), *Creseis* (Sea butterfly).

Class 5. Pelecypoda or Lamellibranchiata or Bivalvia (Gk. *pelekus– hatchet, podos–* foot). Shell is made up of two halves. **Examples :** *Unio, Mytilus* (Sea mussel), *Teredo* (shipworm), *Ensis* (razor shell or razor clam), *Solen* (razor fish or razor shell), *Ostrea* (edible oyster), *Pecten* (scallop), *Pinctada* (Pearl oyster).

Class 6. Cephalopoda (Gk. *kephale*– head, *podos*– foot). Head and foot regions are combined and modified into a structure which has eyes and eight tentacles, hence the name cephalopod or 'head foot'. Cephalopods are regarded at the top of invertebrates evolution in terms of learned behaviour they exihibit. Shell is external (*Nautilus*), internal (*Sepia*) or absent (*Octopus*). **Examples :** *Sepia, Loligo, Octopus, Nautilus* (Pearly nautilus). Some cephalopods are the largest invertebrates.

Evolutionary Precursor of Molluscs. A "living fossil" named *Neopilina* discovered in

1952 from the Pacific ocean, shows metameric segmentation which is not a characteristic of molluscs. *Neopilina* has 8 pairs of muscles, 5 or 6 pairs of gills, and 5 pairs of nephridia. Metameric segmentation and presence of the trochophore larva in both annelids and molluscs suggest that molluscs have descended from the annelids. Thus, the annelids are the evolu-

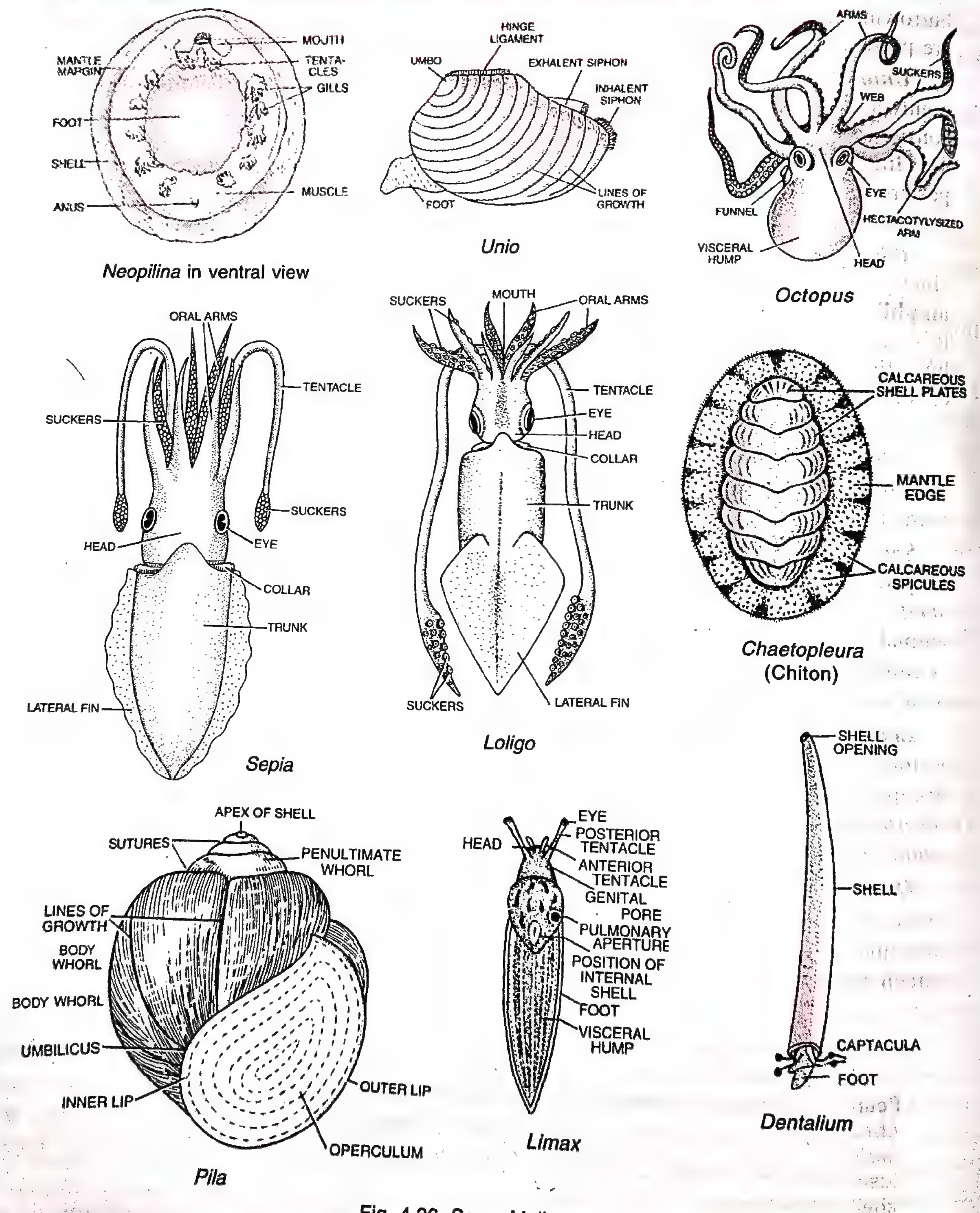


Fig. 4.36. Some Molluscs.

tionary precursor of molluscs. *Neopilina* is a **"connecting link"** between Annelida and Mollusca.

Chaetopleura **(Chiton)— The Coat of Mail Shell.** Chiton is marine and found attached to rocks by its foot. The shell consists of a row of eight plates.

Dentalium— **The Elephant's tusk-shell.** It is a marine mollusc. *Dentalium* is found burrowing in sand. The shell is slightly curved, tubular and opens at both the ends. There are present filamentous tentacles called the **captacula**, which are useful in feeding.

Unio **(Fresh Water Mussel).** It is found in rivers, lakes and ponds. The animal is omnivorous feeding on microscopic organisms. Its larva lives as parasite on fish. Its shell consists of two halves, called the **valves.** A whitish elevation in each valve is called **umbo.** The **lines of growth** indicate the age of the individual. There are present two siphons posteriorly. It acts as scavenger and keeps water clean. Its shell yields an excellent quantity of lime. The shells of the fresh water mussels are used in the manufacture of buttons.

Pila **(Apple snail).** It inhabits ponds, paddy fields, sometimes streams and rivers. It is chiefly herbivorous and feeds on aquatic plants like *Pistia* and *Vallisneria.* It leads an **amphibious** life respiring by means of gill in water and by a plumonary sac an land. Thus it is adapted for both aquatic and terrestrial life. The mouth or aperture of the shell is closed by a flat and oval plate, the **operculum**. Pila has **osphradium** which is meant for testing chemical and physical nature of water. The buccal cavity of *Pila* contains a rasping organ, the **radula,** with transverse rows of teeth for cutting the grasses.

Limax **(Grey Slug).** It is terrestrial and is abundantly found in gardens, cultivated lands and over damp soil. It is nocturnal and herbivorous. *Shell is internal.* It is a hermaphrodite animal. The slug is a plant pest. It damages seedlings, tender shoots and leaves.

Sepia— **(Cuttle fish).** It is a marine and a good swimmer. In male the left arm is spoon shaped and is called **hectocotylized** which is used to tranfer sperms into the female. *The shell is internal.* A pear-shaped **ink-sac** containing the ink-like fluid is present. When the animal is attacked ink-like fluid is ejected through the funnel to form a smoke cloud. Sepia is edible. Sepia ink obtained from this animal is used by artists. The shell of sepia is used as a source of calcium for pet birds.

Loligo **(Squid).** Like Sepia, it is also found in the warm seas. It also ejects a dark ink to form a smoke cloud to escape from the enemy. Its body resembles that of *Sepia* in form except that it is narrower than that of *Sepia*. It also has *internal shell. Largest living invertebrate is* **giant squid** (*Architeuthis*) upto 18 meters long. *Loligo* is edible. *The giant squid has the largest eye in the animal kingdom.*

Octopus **(Devil fish).** It is also marine. It kills its prey with poisonous saliva. One of the arms of male is spoon shaped and is called **hectocotylized** which is used to transfer sperms into the female. *The shell is absent. Octopus* ejects an inky fluid in water and forms a screen for defence from its enemies. *Octopus* can change its colour.

ADDITIONAL INFORMATION

- **Pearl formation.** Best quality pearls are obtained from pearl Oyster (*Pinctada vulgaris, P. margaritifera*). It is sedentary mollusc which is now reared artificially. The shell is opened and a fine silica or other particle is introduced between the mantle and the shell. The mantle starts secreting nacre over the foreign particle. In a few years (usually seven) it grows to the size of a pearl. The same is extracted from the oyster. Pearl formation was introduced in Japan by **Mikimoto**. Japan has surpassed all other countries in pearl production.

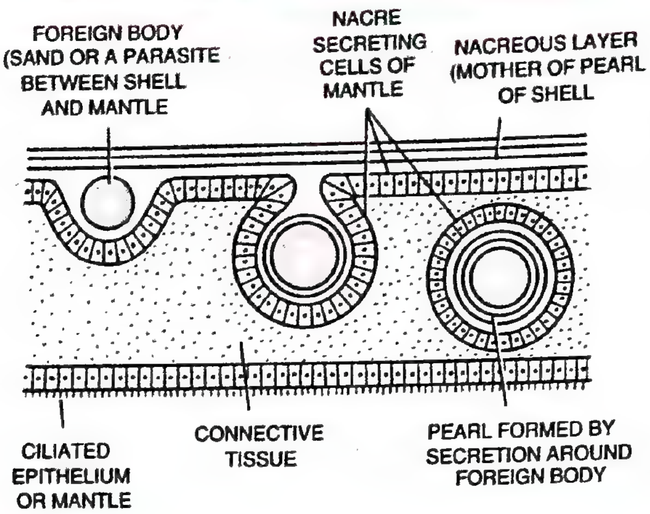


Fig. 4. 37. Stages in pearl formation.

- In *Unio* rectum passes through heart
- *Cypraea* is commonly known as 'Cowrie'. Cowrie shells are used in India in an indoor game, called 'chowpad'.
- **Organs of Bojanus** refer to the Kidneys of the fresh water mussel.
- **Malacology**— Study of molluscs.
- **Conchology**— Study of shells of molluscs.
- Molluscs with internal shell- *Limax, Aplysia, Sepia, Loligo.*
- **Molluscs without shell** — *Doris, Octopus.*
- Ammonites are fossil shell remains of cephalopods.
- **Shell fishes.** A shell fish has a shell in two halves. Examples : mussels, oysters, etc. They are molluscs and are used for food.
- **Ordovician Period.** "Age of invertebrates" (also called "Age of Giant Molluscs").
- Cephalopods (*e.g.,* Squid and Octopus) are some of most intelligent invertebrates.
- **Aplysia (Sea hare)** feeds mainly on the sea weeds.
- **Nautilus** is commonly called as **Pearly Nautilus.** It is used extensively for ornamental purposes.

Phylum Echinodermata— the Spiny Skinned Animals

(Gk. *echinos*– spines; *derma*– skin/covering)

Jacob Klein (1738) introduced the name "**Echinodermata**". About 6000 species belong to the phylum Echinodermata.

General Characters

1. **Habitat.** *All existing echinoderms are marine.* They generally live at sea bottom. Some are pelagic (free swimming in open water) and a few are sessile (attached to the substratum).

2. **Body Form.** It varies considerably. The body is star-shaped, spherical or cylindrical. It is unsegmented. The body lacks head.

3. **Spines and Pedicellariae.** Many echinoderms bear spines and pincer-like **pedicellariae.** The **spines** are protective in function. The pedicellariae keep the body surface clear of debris and minute organisms.

4. **Symmetry.** The symmetry is bilateral in larvae but **pentamerous radial** in adults, *i.e.,* body parts are arranged in fives or multiples of five.

5. **Body Wall.** Epidermis is single layered and ciliated. In many echinoderms there is **endoskeleton** of calcareous plates in the dermis which are *mesodermal in origin.*

6. **Body Cavity.** There is a true **enterocoelic coelom.**

7. **Ambulacral System (= Water Vascular System).** *Presence of ambulacral system is the characteristic feature of phylum echinodermata.* A perforated plate called **madreporite** is present in this system. The pores of the madreporite allow water into the system. **Tube feet** of this system help in locomotion, capture of food and respiration. Water vascular system is of *coelomic origin.*

8. **Digestive Tract.** It is usually complete. Brittle stars have incomplete digestive tract.

9. **Haemal** and **Perihaemal Systems**. Instead of blood vascular system, there are present haemal and perihaemal systems which are of *coelomic origin*. Thus the so called circulatory system is open type and includes haemal and perihaemal systems. The so called blood is often without a respiratory pigment. There is no heart.

10. **Respiratory Organs**. Gaseous exchange occurs by **dermal branchae** or **papulae** in star fishes, **peristominal gills** in sea urchins, **genital bursae** in brittle stars, and **cloacal respiratory trees** in holothurians. Exchange of gases also takes place through tube feet.

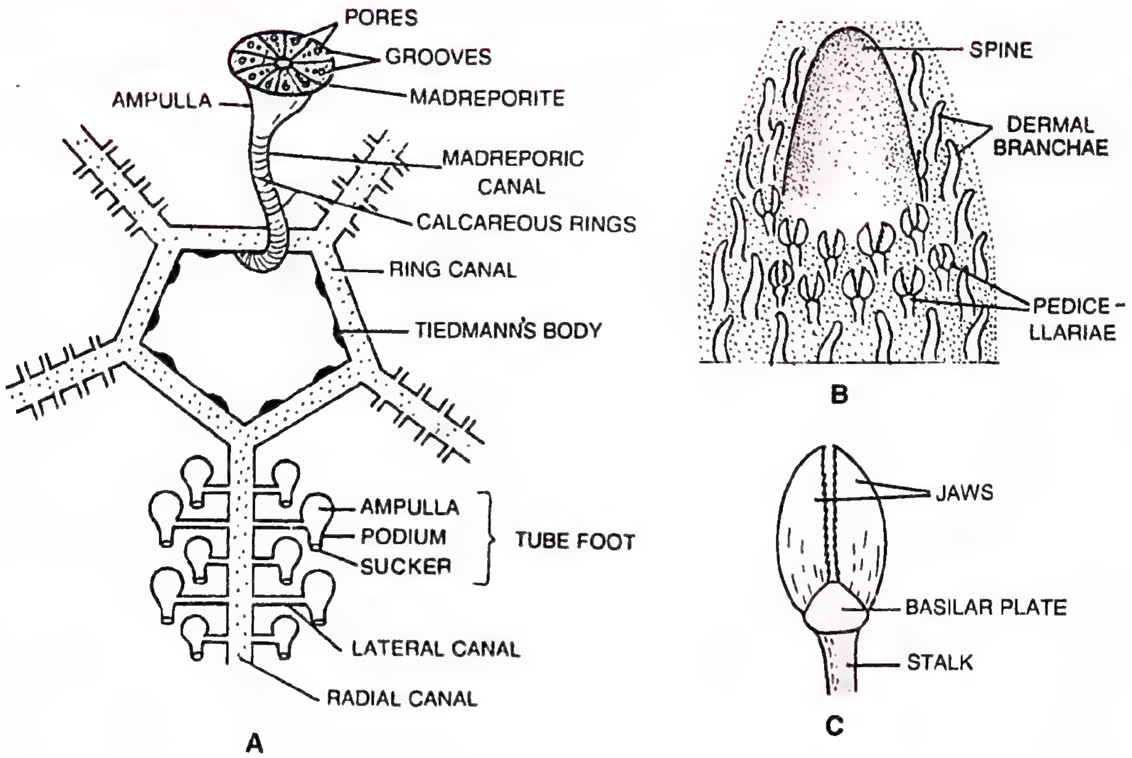


Fig. 4.38. A, Water vascular system of star fish; B, Pedicellariae spine and dermal branchae. C, Pedicellaria with parallel jaws.

11. **Excretory Organs**. Specialized excretory organs are absent. Nitrogenous wastes are diffused out via gills. Ammonia is chief excretory matter.

12. **Nervous System**. It consists of a **nerve ring** and **radial nerve cords**. Brain as such is absent.

13. **Sense Organs**. They are poorly developed.

14. **Sexes and Fertilization.** Except a few individuals, the sexes are separate. There is no sexual dimorphism. Fertilization is usually external.

15. **Asexual Reproduction**. Some forms reproduce asexually by self-division.

16. **Autotomy** and **Regeneration**. Phenomena of autotomy and regeneration are often well marked in echinoderms.

17. **Development**. The development is indirect and includes a ciliated, bilaterally symmetrical larva that undergoes metamorphosis to change into the radially symmetrical adult. Different larval forms are found which are mentioned in the classes of Echinodermata.

Unique Features. (i) Presence of spines and pedicellariae. (ii) Ambulacral system (water vascular system). (iii) Haemal system. (iv) Mesodermal endoskeleton of calcareous plates. (v) Bilateral symmetry in the larva and radial symmetry in the adult.

Degenerate Characters. (i) Lack of head. (ii) Simple sense organs. (iii) Incomplete digestive tract in some forms. (iv) Reduced circulatory system. (v) Absence of excretory system.

Resemblance with Chordates. (i) Radial and indeterminate cleavage. (ii) Gastrulation by invagination. (iii) Mouth derived as an ectodermal invagination. (iv) Adult anus derived from embryonic blastopore. (v) Mesodermal endoskeleton. (vi) Enterocoelous coelom. (vii) Both are deuterostomes. From these resemblances, it is clearly proved that the Echinoderms are nearer to the Chordates than any other group. It also indicates that the chordates have been evolved from Echinoderm-like ancestors.

Classification. Phylum Echinodermata is divided into five classes.

Class 1. Asteroidea (Gk. *aster*– star, *eidos*– form). Body is star-like. Five arms are usually present which are not sharply marked off from the central disc. Larval forms are **Bipinnaria** and **Brachiolaria. Examples :** *Asterias* (Star fish), *Pentaceros* (Star fish), *Astropecten* (Star fish).

Class 2. Ophiuroidea (Gk. *Ophis*– snake, *Oura*– tail, *eidos*– form). Body is star-like. Arms are sharply marked off from the central disc. Ambulacral grooves are absent. Pedicellariae are absent. Larval form is **Ophiopluteus. Examples :** *Ophiothrix* (brittle star), *Ophioderma* (brittle star), *Ophiocoma* (brittle star), *Ophiura* (brittle star).

Class 3. Echinoidea (Gk. *echinos*– hedgehog, *eidos*– form). Body is globular or disc-like. Biting and chewing apparatus with teeth called **Aristotle's Lantern** is present. Ambulacral grooves are absent. Larval forms are **Pluteus** and **Echinopluteus. Examples :** *Echinus* (sea-urchin), *Clypeaster* (cake urchin), *Echinarachinus* (sand dollar), *Echinocardium* (heart urchin).

Class 4. Holothuroidea (Gk. *Holothurion*– sea cucumber, *eidos*– form). Body is elongated and cylindrical. Oral end has mouth surrounded by tentacles. Ambulacral grooves are absent. Spines and pedicellaria are absent. Larval forms are **Auricularia** and **Doliolaria. Examples :** *Holothuria* (sea cucumber), *Cucumaria* (sea cucumber).

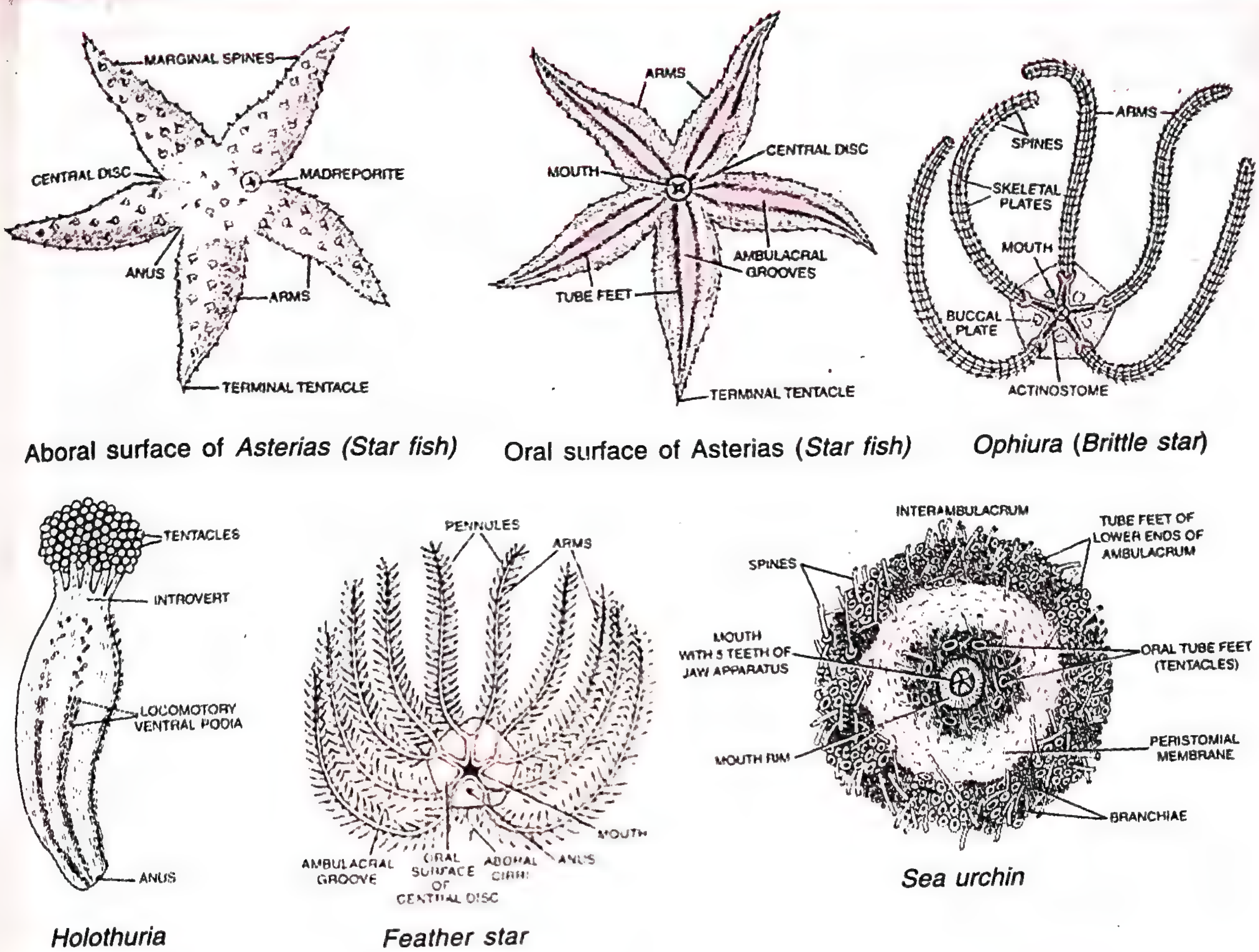
Class 5. Crinoidea (Gk. *Crinon*– lily, *eidos*– form). Body has a central disc which is attached to the substratum. *Arms are branched.* Spines and pedicellariae and madreporite are absent. Larval form is **Doliolaria.** They are commonly called feather stars or sea lilies. **Example :** *Antedon* (feather star), Sea lilies.

Asterias* (Star Fish).** It possesses great power of regeneration and shows autotomy. At the terminal end of each ambulacral groove lies a bright red ***eye. The aboral surface bears many stout **spines** distributed irregularly. In between the spines, there are present soft **dermal branchiae**. They act as respiratory and excretory organs. In between two arms near the anus, there is present a perforated circular plate, the **madreporite.** There are present microscopic pincer-like structures known as **pedicellariae**. They also act as organs of offence.

***Ophiura* (Brittle star).** Brittle stars also swim like snake with their arms. Anus is absent.

***Echinus* (Sea urchin).** It moves with the help of spines. The sea urchin has a masticatory apparatus, called **Aristotle's Lantern** because of its resemblance to ancient Greek ship lantern. It is formed by five strong and sharp teeth.

***Cucumaria* (Sea cucumber).** The sea cucumbers respire by **respiratory trees** in the cloaca. For this, water is drawn in and expelled through the anus alternately. The mouth is anterior and is surrounded by tentacles.



Aboral surface of *Asterias (Star fish)* — Oral surface of Asterias (*Star fish)* — *Ophiura* (*Brittle star*)

Holothuria — *Feather star* — *Sea urchin*

Fig. 4.39. Some Echinoderms.

***Antedon* (Feather star).** It has great power of autotomy and regeneration. The body comprises a cup shaped central **disc** and five slender arms. Each arm is bifurcated, bearing a row of **pinnules** on each side. It is attached to the substratum.

ADDITIONAL INFORMATION

- Endoskeleton in echinoderms is unique in being a mesodermal structure instead of ectodermal as in other invertebrates.
- **Cuverian Organs**. In *Holothuria*, the lower branches of the respiratory trees are modified into **Cuverian organs** which secrete a sticky secretion for defence.
- Star fishes do very well with no brain at all.
- ***Auricularia*** is connecting link between non-chordata and chordata.

Phylum Hemichordata

(Gk. *hemi–* half, *chordata–* notochord)

Due to some similarities with chordates, some workers (**Bateson,** 1885) considered Hemichordata as a subphylum under phylum chordata. But, on grounds of its general organization, recent scientists, like **Van der Horst** (1939), **Dawydoff** (1948), **Marcus** (1958) and **Hyman** (1959), have given it the status of a phylum under nonchordata. The name "Hemichordata" is, however retained for the group.

General Characters

1. **Habitat.** They mostly live in burrows and are *exclusively marine.*
2. **Body Form.** Body is soft, worm-like and is divisible into *proboscis, collar* and *trunk.*
3. **Body wall.** It is with a single layered epidermis.
4. **Coelom.** The hemichordates are *enterocoelous.*
5. **Stomochord.** It is a *hollow outgrowth,* arises from the roof of the buccal cavity, called "buccal diverticulum". It is present in the proboscis.
6. **Digestive Tract.** It is complete.
7. **Gill Slits.** These are narrow openings in the pharynx. When gill slits are present, they are one to several pairs. Gill slits are *dorsal in position.* They are lateral in chordates.
8. **Respiration.** Respiration takes place through branchial portion of pharynx bearing gill slits.
9. **Blood Vascular System.** It is "*open type*", usually with a contractile heart vesicle and two longitudinal vessels, one dorsal and one ventral, interconnected by lateral vessels and sinuses. Blood is colourless.
10. **Excretory organ.** It is a single *proboscis gland* or **glomerulus** situated in the proboscis.
11. **Nervous system.** It is primitive, consisting mainly of an intraepidermal nerve plexus. *Balanaoglossus* has both dorsal nerve cord and ventral nerve cord.
12. **Sense organs.** Sensory cells of the epidermis act as sense organs.
13. **Reproduction.** It is mostly sexual. Sexes are separate or united. Gonads are one to several pairs. Fertilization is external.
14. **Development.** Except in some forms development is mostly indirect through a free swimming **tornaria larva.** Examples: *Balanoglossus, Saccoglossus, Cephalodiscus* and *Rhabdopleura.*

***Balanoglossus*— The Ancorn or Tongue Worm.** It is a marine animal which lives in U-shaped burrows in the bottom sand. It feeds on organic matter ingested along with sand. It is unisexual. Fertilization is external. Life cycle includes a tornaria larva. Power of regeneration is well marked.

It is worm like animal. The body is divisible into three regions. (i) **Proboscis.** It appears as a tongue-like projection, hence the name "tongue worm". (ii) **Collar.** It is the muscular region which bears **mouth** ventrally below the proboscis stalk. (iii) **Trunk.** It is divisible into three regions (a) The anterior **branchiogenital region** which has gill pores and gonads. The lateral regions containing the gonads are thin and flat and form **genital wings.** (b) The middle **hepatic region** is marked externally with irregular elevations due to sacculations formed by projecting **hepatic caeca** of the intestine. (c) The posterior **abdominal region** gradually tapers posteriorly and bears a terminal **anus.**

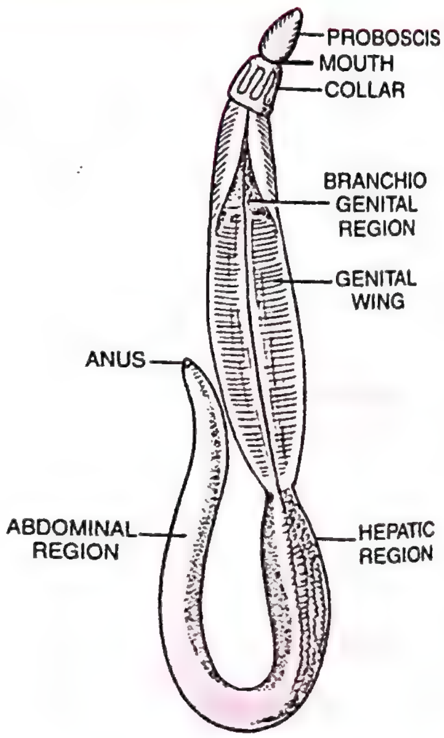


Fig. 4.40. *Balanoglossus.*

Asexual Reproduction in Animals

1. **Binary fission**. Binary fission is the division of the parent animal into two nearly equal sized daughter individuals. It occurs in *Planaria*.

2. **Budding**. An outgrowth called bud appears due to multiplication of cells in the ectodermal layer. The bud grows in size. It is pinched off from the parent organism and establishes itself. Budding is common in *Hydra* and sponges.

3. **Fragmentation**. The body of the parent may break into some pieces. Each piece develops into a whole animal. It is called fragmentation. It occurs in *Planaria* and Sponges.

4. **Gemmule Formation**. In the fresh water sponge (*e.g., Spongilla*) and a few marine sponge, buds are formed within the parent's body. They are called **gemmules** (= internal buds). Gemmules come out of the sponge. The cells (**archaeocytes**) of gemmule form a sponge.

5. **Strobilation**. During development, the **gastrula** changes to the **planula** (larva) in *Aurelia* (a jelly fish). The planula forms another larva, the **scyphistoma**. In winter and spring, the scyphistoma undergoes a process of **transverse fission** to form a number of **ephyrae** (larvae) so that the scyphistoma assumes the appearance of a pile of saucers. The division of the scyphistoma larva of *Aurelia* into a number of ephyrae larvae by a series of transverse fissions is called **strobilation.** The ephyrae are detached and feed and grow. In due course of time the ephyrae metamorphose into jelly-fishes. Strobilation also occurs in the neck of *Taenia*.

CHORDATES

Diagnostic Characters of Chordates

All the chordates possess four diagnostic characters either in the embryonic or adult stage.

1. **Notochord.** It is a solid unjointed, stiff but flexible rod-like structure situated on the dorsal side between the dorsal hollow nerve cord and the alimentary canal.

2. **Dorsal Hollow Nerve Cord.** The nerve cord of chordates is always hollow and lies dorsal to the notochord.

3. **Pharyngeal Gill Slits.** All the chordates have at some stage of life, a series of paired narrow openings, the *gill slits on the lateral sides of the pharynx.*

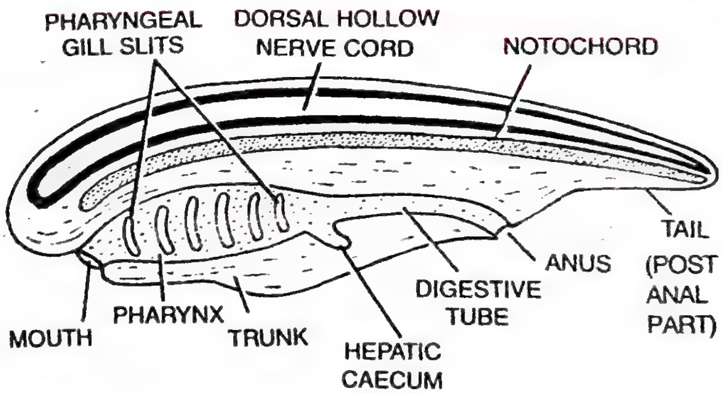


Fig. 4.41. A generalized chordate.

4. **Tail.** It is a post-anal part of the body which is reduced or absent in many adult chordates.

Other Characters of Chordates

These include bilateral symmetry, three germinal layers, segmentation, organ-system level of organisation, cephalization, coelom, endoskeleton, complete digestive tract, special organs for respiration and excretion, closed circulatory system, separate sexes, gonads with gonoducts and without asexual reproduction.

Differences between Chordates and Non-chordates

Chordates	*Non-Chordates*
1. A notochord is present at some stage in the life of a chordate.	1. Notochord is not present at any stage in the life of a non-chordate.
2. Central nervous system is dorsal and hollow.	2. Central nervous system is ventral and solid.
3. Gill slits are present in the pharynx either in the embryo or adult.	3. Gill slits are absent.
4. Tail is present at some stage in the life of the chordate.	4. Tail is absent.
5. Heart is ventral.	5. Heart is dorsal (if present).
6. If present RBCs contain respiratory pigment (haemoglobin).	6. If haemoglobin or other respiratory pigment is present, it is found in the blood plasma. RBCs are absent.

Outline Classification of Phylum Chordata

Phylum Chordata

- **Subphylum Urochordata** *e.g., Herdmania*
- **Subphylum Cephalochordata** *e.g., Amphioxus*
- **Subphylum Vertebrata**
  - Section Agnatha — Jawless vertebrates
    - **Class Ostracodermi** (Extinct)
    - **Class cyclostomata** *e.g., Petromyzon, Myxine*
  - Section Gnathostomata — Jawed vertebrates
    - **Superclass Pisces** — True fishes
      - **Class Placodermi** — All fossils, had protective scales or plates, *e.g., Climatius*
      - **Class Chondrichthyes** — Cartilaginous fishes *e.g., Scoliodon*
      - **Class Osteichthyes** — Bony fishes, *e.g., Labeo*
    - **Superclass Tetrapoda** — Typically four limbs
      - **Class Amphibia** *e.g., Uraeotyphlus,* Salamander, Frog
      - **Class Reptilia** *e.g.,* Tortoise, Lizards, Snakes, Crocodile
      - **Class Aves** *e.g.,* Birds
      - **Class Mammalia** *e.g.,* Mammals

Sub-Phylum 1. Urochordata (Gr. *uros*– tail + *chordata* = notochord)

(i) Adults are generally sedentary (fixed to substratum). (ii) This sub-phylum is also called **Tunicata** because the adult body is enclosed within a leathery **test** or **tunic** formed of a cellulose-like organic substance termed **tunicin.** (iii) The notochord is only present in the tail of the larva and disappears in the adult. (iv) The dorsal tubular nerve cord is found in the larva. It is replaced by a dorsal ganglion in the adult (v) The pharynx is perforated

by numerous apertures called **stigmata** formed by the larval gill slits. The stigmata open into an ectoderm lined cavity, the **atrium.** (vi) The larva (**tadpole**) is motile and undergoes **retrogressive metamorphosis**, *i.e.*, change from better developed larva to less developed adult. **Examples.** *Herdmania* (Sea Squirt), *Ascidia, Ciona, Doliolum, Salpa, Botryllus* (colonial urochordate), *Molgula, Pyrosoma. Pyrosoma* is bioluminescent colonial urochordate. *Herdmania* has valveless heart. The blood of *Herdmania* is green due to the presence of **vanadium** in blood.

- Excretory organ in *Herdmania and Ascidia* – **Neural gland.**

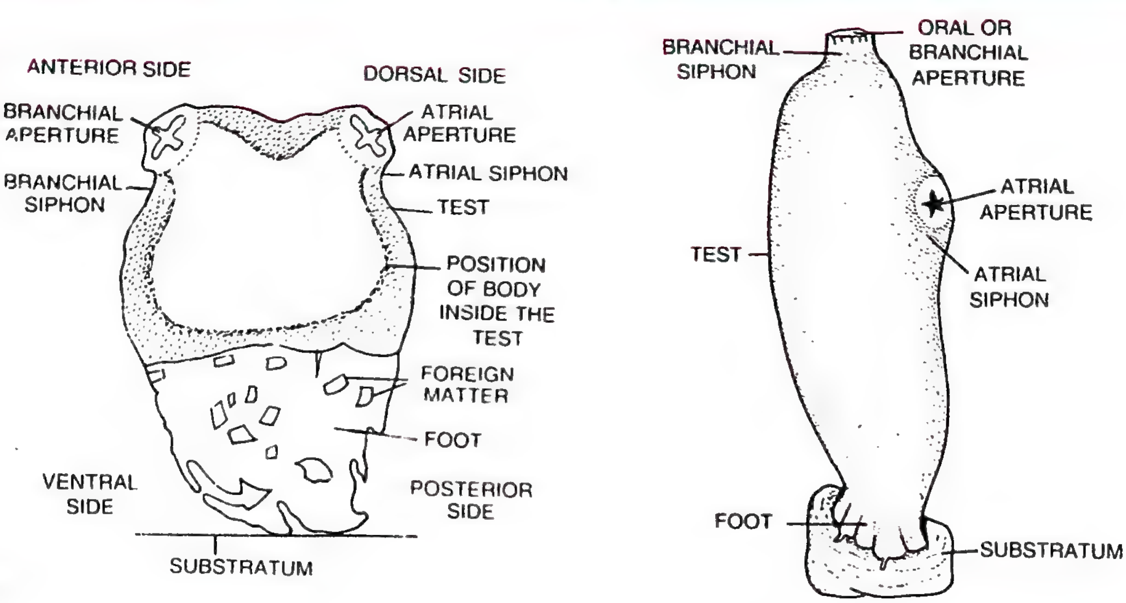


Fig. 4.42. Two Urochordates. *Left Herdmania, Right Ascidia.*

Ascidia. It is closely similar to *Herdmania*. It is marine, solitary and sedentary, living in temperate seas. The body is attached to the substratum by a foot. Test is thick and tough and branchial siphon and atrial siphon are short. There is a motile tailed tadpole (larva) which undergoes retrogressive metamorphosis to become sessile adult.

Sub-phylum 2. Cephalochordata (Gr. *cephalos*– head + *chordata* = notochord)

(i) Both the adult and larva are motile. (ii) The notochord extends upto anterior end of the body hence this subphylum is named. (iii) The notochord persists throughout life. (iv) Pharyngeal gill slits are more numerous and are better developed.(v) Atrium is also present. (vi) The tail is present throughout life. (vii) It shows progressive metamorphosis (change

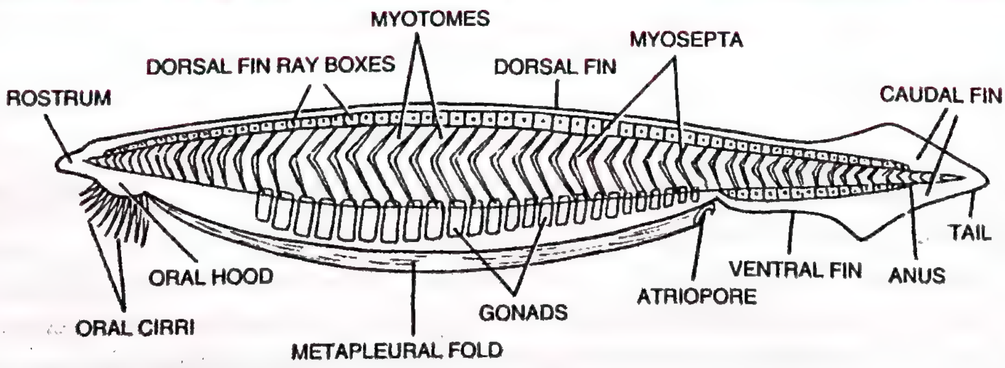


Fig. 4.43. *Amphioxus.*

from less developed larva to better developed adult). **Example.** *Branchiostoma* (= Amphioxus). *Amphioxus* has both ends pointed like lance hence it is commonly called **lancelet.** *Amphioxus* has numerous **eye spots** or **ocelli** which are sensitive to light.

Subphyla Urochordata and Cephalochordata are often referred to as **protochordates** or **acrania** (without cranium — brain box).

Differences between Urochordata and Cephalochordata

Urochordata	*Cephalochordata*
1. The notochord is present only in the tail of the larva and disappears in the adult.	1. The notochord is present throughout life and extends from the anterior end to the posterior end of the body.
2. Adult is mostly sedentary.	2. Adult has fins that help in swimming.
3. Nerve cord is only found in the larva. It is replaced by a dorsal ganglion in the adult.	3. Nerve cord is well developed in adult too.
4. The larva undergoes retrogressive metamorphosis. Example : *Herdmania*.	4. The larva undergoes progressive metamorphosis. Example : *Branchiostoma* (*Amphioxus*).

Sub-phylum 3. Vertebrata or Craniata

(1) These are advanced chordates that have **cranium** (brain box) around brain. (2) Notochord is only present in the embryonic stage, it is replaced by a cartilaginous or bony **vertebral column** in the adult forms. (3) There is very high degree of **cephalization** (formation of head). (4) The **epidermis** consists of many layers of cells. Epidermis may bear an **exoskeleton** of **scales, feathers** or **hair**. (5) Three types of **muscles,** striped, unstriped and cardiac, are present. (6) **Coelom** is well developed. (7) **Digestive tract** is complete. (8) The **endoskeleton** is formed of cartilage or of cartilage and bone. (9) Heart is ventrally situated with two, three or four chambers. There is present **hepatic portal system.** (10) There is closed **circulatory system** consisting of blood vascular and lymphatic systems. RBCs are present. (11) **Respiratory organs** may be gills, skin, buccopharyngeal cavity and lungs. (12) A pair of **kidneys** is present for excretion and osmoregulation. (13) **Nervous system** consists of central nervous system (brain and spinal cord), peripheral nervous system (cranial and spinal nerves) and autonomic nervous system (sympathetic and parasympathetic nervous systems). (14) **Sense organs** are eyes, ears, tongue, nasal chambers, and skin. In some vertebrates **lateral line system** is present. (15) **Cranial nerves** are 8, 10 or 12 pairs. (16) **Endocrine glands** are found in all vertebrates. (17) Sexes are separate (unisexual) except hag fish, which is bisexual. There is no asexual reproduction.

Subphylum Vertebrata is divided into two sections : Agnatha and Gnathostomata.

Section 1. Agnatha (The Jawless Vertebrates). The mouth does not possess jaws hence named agnatha. Notochord persists throughout life. Vertebral column is represented only by small imperfect neural arches over the notochord. They do not have paired appendages. They have single nostril. Internal ear has one or two semi-circular canals. They are cold blooded. Agnatha has two classes : Ostracodermi and Cyclostomata.

Class 1. Ostracodermi (Extinct). They are the *earliest known vertebrates* which appeared in Ordovician period. They had well developed dermal scales which led to their names "Ostracoderms"— bony skin. They are also called "armoured fishes". All are extinct. Examples : *Cephalaspis, Pteraspis*, etc.

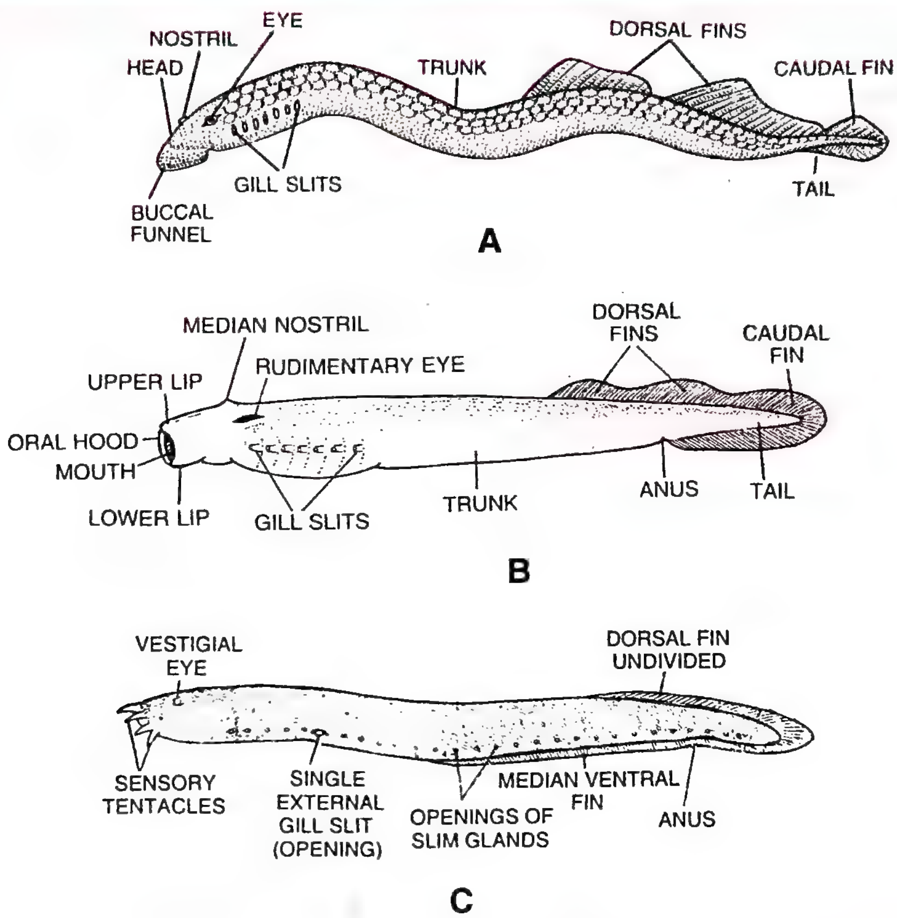


Fig. 4.44. *A, Petromyzon*. B, Ammocoete (Larva). C, *Myxine*.

Class 2. Cyclostomata (The Circular mouthed fishes; Gr. *cyklos*–circular; *stome*–mouth). (1) They occur in the seas and large rivers. If cyclostomes are marine they migrate for spawning to fresh water. After spawning within a few days, they die. Their larvae, after metamorphoses return to the ocean. (2) The mouth is circular and jawless. They are also called **jawless fishes** (*not true fishes*). (3) They have 6–15 pairs of **gill slits**. (4) Head and brain are poorly developed. (5) Unpaired fins are present. (6) Endoskeleton is cartilaginous. (7) Kidneys are mesonephric. (8) Stomach is absent. (9) Respiratory organs are gills. (10) Heart is two chambered (one auricle and one ventricle). (11) There are 10 or 8 pairs of cranial nerves. (12) Lateral line sense organs are present. (13) Fertilization is external. Life history may include a larva named **ammocoete**.

Example. *Petromyzon* **(Lamprey),** *Myxine* **(Hagfish).**

Comparison between Lamprey and Hagfish (Fig. 4.46)

Characters	Lamprey (*Petromyzon*)	Hagfish (*Myxine*)
1. Habitat	Marine as well as fresh water	Exclusively marine
2. Parasitism	Both parasitic (Ectoparasite) and nonparasitic species	Only parasitic (Ectoparasite) species
3. Feeding	Sucks out blood of host fishes	Primarily scavenger, feeds mostly upon dead fishes.
4. Breeding	Marine form migrates to fresh water river and stream for spawning (anadromous)	Spawning on sea floor.
5. Body	Stout	Feeble
6. Size	May reach upto 1 metre.	Remains under 1 metre.

7. **Fins**	Two dorsal fins.	Dorsal fin single or absent.
8. **Skin**	Less slimy	More slimy, hence called "slime eel"
9. **Paired eyes**	Functional	Degenerate
10. **Mouth**	Ventral	Terminal
11. **Buccal funnel**	Present	Absent
12. *Tongue*	Less developed with larger teeth	More developed with smaller teeth
13. **Salivary glands**	Present and secrete an anticoagulant	Absent
14. **External gill slits**	7 pairs	1 pair
15. **Brain**	Better developed	Poorly developed
16. **Cranial nerves**	10 pairs	8 pairs
17. **Sexes**	Separate (unisexual)	United (Hermaphrodite = bisexual)
18. **Development**	Indirect with **ammocoete** (larva), metamorphosis is present	Direct, without larva, no metamorphosis

Section 2. Gnathostomata (The Jawed Vertebrates). Mouth has jaws hence it is named gnathostomata. Embryonic notochord is usually replaced in adult by a vertebral column. Paired fins or limbs are present. Paired nostrils are present. Internal ear has three semicircular canals.

Differences between Agantha and Gnathostomata

Agnatha	*Gnathostomata*
1. Mouth is without jaws.	1. Mouth has jaws.
2. Paired appendages are not present.	2. Paired appendages (fins or limbs) may be present.
3. Notochord is present throughout life.	3. Notochord is present in the embryonic stage and in adult it is replaced by a vertebral column.
4. There are 8 or 10 pairs of cranial nerves.	4. There are 10 or 12 pairs of cranial nerves.
5. Only a single median nostril is present.	5. Paired nostrils are present.

Gnathostomata is divided into two super classes : **Pisces** and **Tetrapoda.**

Super class 1. Pisces (Bear Fins). It includes **true fishes** and divided into three classes:

Class 1. **Placodermi.** Body had an external protective armour of bony scales or plates, *e.g., Climatius.*

Fig. 4.45. *Climatius.*

Class 2. **Chondrichthyes.** This class includes cartilaginous fishes, *e.g., Scoliodon, Torpedo, Chimaera,* etc.

Class 3. **Osteichthyes.** It includes bony fishes, *e.g., Labeo, Hippocampus,* etc.

Super class 2. Tetrapoda (Bear Limbs). Typically all tetrapods (Gk. *Tetra* – four + *podos* = foot) possess two pairs of limbs.

Differences between Pisces and Tetrapoda	
Pisces	*Tetrapoda*
1. Fishes have paired appendages in the form of pectoral and pelvic fins.	1. Tetrapods have paired appendages in the form of limbs.
2. Fishes respire by means of gills.	2. Tetrapods respire by lungs. Some amphibians also respire by buccopharyngeal cavity, skin and gills.
3. Except lung fishes they do not have internal nares.	3. They have internal nares.
4. Heart is 2 chambered except lung fishes where heart is 3 chambered.	4. Heart is three or four chambered.
5. Fishes have internal ear.	5. Tetrapods may have internal and middle ear or internal, middle and external ear. Snakes do not have ears.

Tetrapoda is divided into four classes : **Amphibia, Reptilia, Aves** and **Mammalia.**

Pisces and Amphibia are called **Anamniotes** (without embryonic membranes). Reptilia, Aves and Mammalia are known as **Amniotes** (with embryonic membranes).

Structure of a Typical (Generalized) Fish

Fishes are cold blooded animals, typically with backbone, gills and fins. The body of a typical fish comprises **head, trunk** and **tail**. The head bears two eyes with well developed nictitating membrane, two internal ears, two nostrils which are closed internally (except in lung fishes) and mouth. Behind the head on each side, there are either gill slits or gills meant for respiration. The gills are usually covered with a lid like structure, the **operculum.** Since the neck is absent the head is continued into the trunk. Paired or unpaired expansions of the skin are called **fins**. Of the paired fins, there are generally anterior **pectoral** and posterior **pelvic fins**, which correspond to our arms and legs respectively. The unpaired fins of the trunk region are generally **dorsal fin** (may be two, rarely three) and **ventral** or **anal fin**, which is present ventrally (near the anus or cloacal aperture). The expanded part of the fin is supported by thin skeletal rods, known as the **fin rays**. The trunk bears **anal** or **cloacal aperture**. The part of the body behind the anus, is designated as **tail**, which is of different shapes in different species. It always has **caudal fin (tail fin)** which is also supported by fin rays. More or less, all the fins are helpful in swimming. A peculiar system of sense organs, the **lateral line system,** is present in the fishes. One lateral line on each side can be seen easily. The body of a fish may or may not be covered with **scales**. The sexes are separate. They are usually oviparous, but ovoviviparous or viviparous forms are also found.

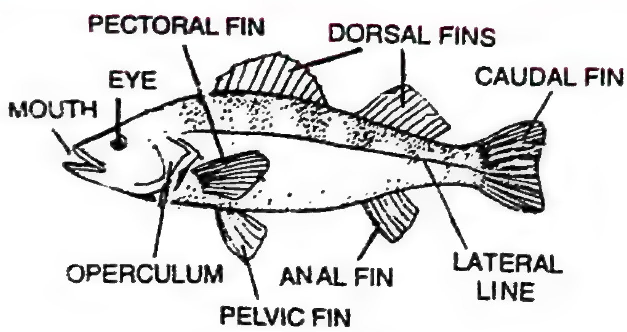


Fig. 4.46. Structure of a Typical Bony Fish.

Class Chondrichthyes— The Cartilaginous Fishes

(Gk. *chondros*– cartilage; *ichthys*– fish)

General Characters

1. The fishes of this class bear cartilaginous endoskeleton. **Notochord** is persistent throughout life. They are cold blooded **(poikilothermous or ectothermic)**. There are about 600 species of cartilaginous fishes.

2. The skin is tough, containing minute **placoid scales**, which are dermal in origin.

3. Except in the *Chimaeras*, the gills are not covered by an operculum (gill cover).

4. Jaws are well developed. Mouth is ventrally placed. A spiral valve called **scroll valve** is usually present in the intestine. The digestive tract leads into the **cloaca.**

5. **External nares** are present on ventral side of the head. The internal nares are absent.

6. Paired fins are broad. The caudal fin is mostly **heterocercal** –asymmetrical (Gr. *heteros*– different).

7. Heart is two chambered (one auricle and one ventricle). Heart has a well developed **sinus venosus** and **conus arteriosus**. There is well developed renal portal system. RBCs are oval and nucleated.

8. Kidneys are mesonephric. Urea is chief nitrogenous waste.

9. The brain bears large **olfactory lobes** and a large **cerebellum.**

10. There are 10 pairs of cranial nerves.

11. Lateral line system is well developed.

12. Lung or air bladder is absent in these fishes.

13. They have internal ears which help the fish keep its balance. The nictitating membrane in the eye of fish is well developed.

14. Some of them have **electric organs** (*e.g.*, *Torpedo*) and some possess **poison sting** (*e.g.*, *Trygon*).

15. They have cloaca. In males, pelvic fins may bear 1 or 2 **claspers** which are used in copulation. The oviducts in cartilaginous fishes are called **Mullerian ducts**. The fertilization is internal. They are oviparous or ovoviviparous (eggs hatch in mother's genital tract). Development is direct.

16. Most of the cartilaginous fishes are marine and most of them are predators.

Examples. *Scoliodon*, *Torpedo*, *Trygon* and *Chimaera*. *Rhinobatus* (guitar fish), *Pristis*, *Zygaena*, *Carcharodon* (Great White Shark).

Chimaera. It is commonly called **rabbit fish, rat fish, ghost fish** or **king of herrings***. It is an interesting fish that *represents the characters of a shark and a bony fish*. Like shark it has cartilaginous skeleton, a pair of pelvic **claspers** and placoid scales . Like bony fish, it possesses **operculum** (gill cover) on each side, and has distinct anus and urinogenital aperture. Cloaca is absent. Male has a **frontal** or **cephalic clasper** on the dorsal surface of the head, its function is unknown.

***Scoliodon* (Dog fish).** In India, *Scoliodon dumerili* is common in the Bay of Bengal. There are present some pores, the **ampullary pores** on the upper and lower surface of the head; each pore leads into an ampulla (pl. ampullae), called **Ampulla of Lorenzini** through which the fish receives information of the temperature fluctuations in the surrounding water.

*Zig zag pattern.

Behind the head on each side there are present five oblique openings, known as **gill slits**, which communicate internally with the pharynx. The caudal fin surrounds the tail, showing asymmetry (upper **epicaudal** lobe and lower **hypocaudal** lobe). Such a type of tail, where two different kinds of lobes are present, is known as **heterocercal tail**. Numerous dermal **placoid scales** are embedded in the skin, which form the exoskeleton of the fish. The male can be distinguished from the female, since the former has a pair of hard elongated **claspers** attached to the pelvic fins. The claspers help in the copulation. It is **ovoviviparous**. *Scoliodon* is also eaten as food by some persons. It yields liver oil.

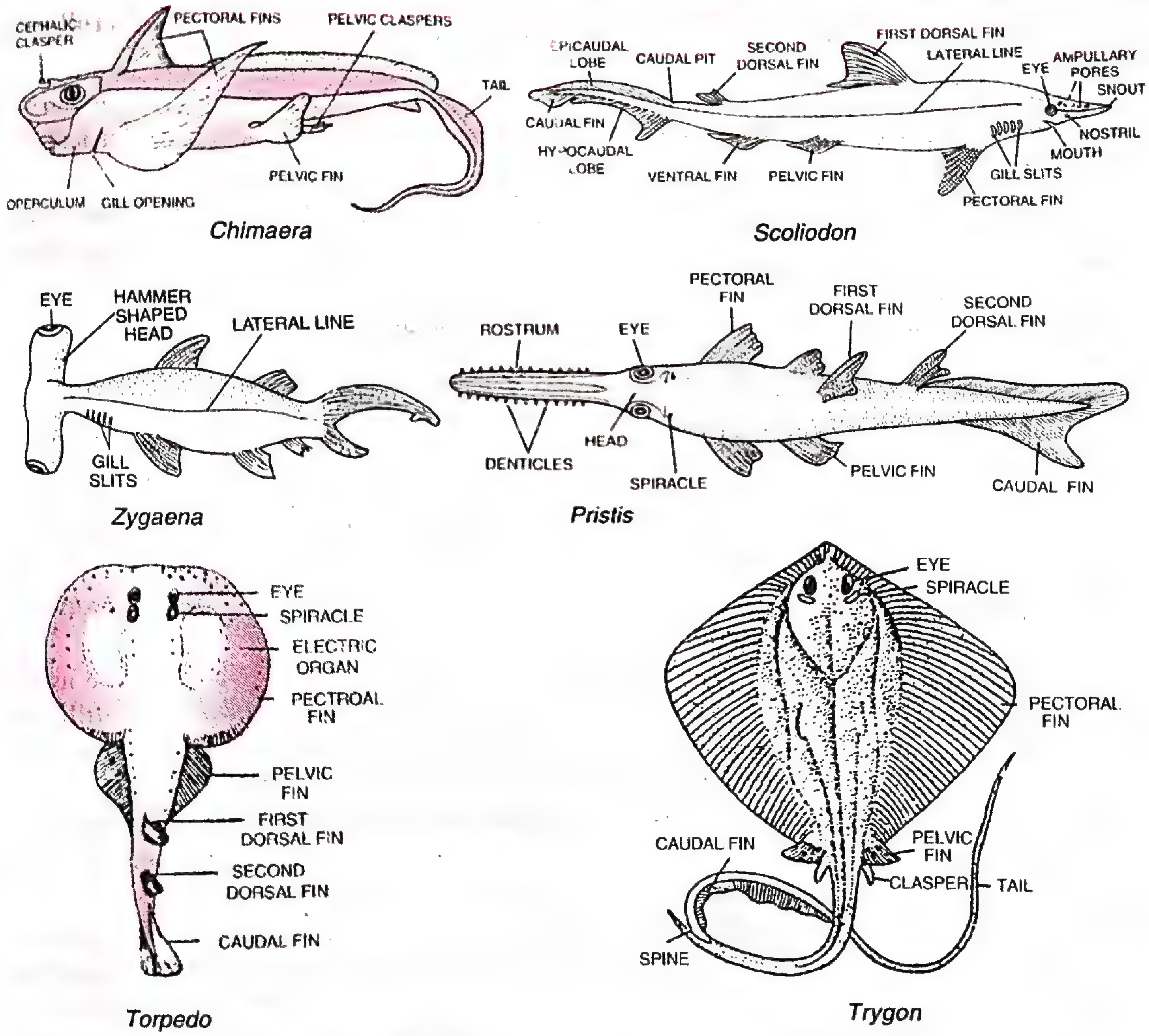


Fig. 4.47. Some Cartilaginous Fishes.

Zygaena (Hammer-Headed Shark). It is a voracious surface feeder and fast swimmer. The head forms two lateral lobes, bearing eyes at their distal ends. The tail has a heterocercal caudal fin. Oil is extracted from its liver.

***Pristis* (The Saw Fish).** The head forms a saw like **rostrum** which bears a series of strong teeth-like **denticles** along the margin. It uses the denticles for offence and defence.

Its body is intermediate between the sharks and the rays. Ventral or anal fin is absent. Caudal fin is heterocercal. The fish is ovoviviparous.

***Torpedo* (Electric Ray).** It is a bottom-living marine fish, discharging electricity which is sufficient to make unconscious the preys such as small fishes, etc. Both the pectoral fins are fused with the trunk. A pair of **electric organs** are situated on the dorsal side of the trunk region. Infact the *electric organs are the modified lateral muscle-plates innervated by the cranial nerves. Torpedo* can generate electric current. The water is drawn through the spiracle and not through the mouth as happens in many fishes.

***Trygon* (Sting Ray).** It resembles the electric ray in many aspects but does not have electric organs. The body is somewhat kite-shaped. The tail is whip-like bearing a **spine** which is modified form of the dorsal fin. The spine or sting makes a severe wound on the victim.

Differences between Shark and Ray

Shark	*Ray*
1. It is a surface feeder.	1. It is a bottom feeder.
2. Body is laterally compressed and spindle shaped.	2. Body is flattened dorsoventrally and disc like.
3. Gill slits are situated on the lateral sides of the body.	3. Gill slits are situated on the ventral side of the body.
4. Pectoral fins are distinct.	4. Pectoral fins are not distinct.
5. Spiracles are not always present *e.g., Scoliodon*.	5. Spiracles are always present *e.g., Torpedo*.

Class Osteichthyes—The Bony Fishes

(Gk. *Osteon*– bone; *ichthys*– fish)

General Characters

1. The endoskeleton is cartilaginous in the embryonic stage, but in the adult forms more or less it is replaced by bones. Thus they have bony endoskeleton. They are ectothermic (cold blooded). There are about 25,000 species of bony fishes.

2. Caudal fin usually **homocercal** –symmetrical (Gr. *homos*– alike).

3. The exoskeleton, if present comprises **cycloid, ctenoid** or **ganoid scales**, which are dermal in origin.

4. The mouth is terminal. Digestive tract leads into an **anus**. Cloaca is absent in bony fishes.

5. External nares lie on the dorsal surface of the snout. In lung fishes internal nares are also present.

6. Bony fishes have a sac-like outgrowth, the **swim bladder** (also called **air bladder**), arising from the dorsal wall of the oesophagus, which is air-filled organ, used to maintain balance and to swim up and down. In some fishes, such as *Heteropneustes*, it helps in respiration.

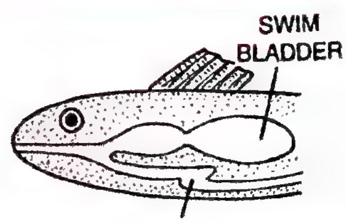


Fig. 4.48. Swim bladder in a bony fish.

7. They have 4 pairs of gills which are covered by an **operculum** on each side.

8. The heart is 2-chambered (one auricle and one ventricle)

and also has **sinus venosus** and **conus arteriosus.** Lung fishes have three chambered heart. (Two auricles and one ventricle). Bony fishes have well developed renal portal system. RBCs are oval and nucleated.

9. Kidneys are mesonephric. Ammonia is chief nitrogenous waste.
10. There are present 10 pairs of cranial nerves.
11. The brain bears relatively small olfactory lobes and cerebellum.
12. Lateral line system is well developed.
13. They have internal ears which helps the fish keep its balance. The nictitating membrane in the eye of fish is well developed.
14. Fertilization is generally external. Most forms are oviparous, some are ovoviviparous. Development is direct except in *Anguilla* (eel) where development is indirect with a larva **leptocephalus.** Some bony fishes show parental care.
15. Bony fishes occur in all sort of waters— fresh, marine, brackish.

Examples. Marine Fishes — *Exocoetus, Hippocampus, Solea, Echeneis* (Sucker fish), *Lophius* (Angler fish), *Stromateus* (Pomfret).

Fresh Water Fishes — *Labeo, Catla, Clarias* (Magur), *Anguilla, Anabas,* Mystus, *Heteropneustes Wallago,* Lung fishes.

Aquarium Fishes — *Betta* (Fighting fish), *Pterophyllum* (Angel fish).

Carps. Carps have toothless mouth with scales on the body, however, head is without scales. Barbels are normally absent, if present, are small or rudimentary. They are mostly herbivorous. Carps are of two types (i) **Major Carps.** They are bigger in size and their growth rate is faster, *e.g., Labeo rohita, Labeo calbasu, Cirrhinus mrigala, Catla catla,Ctenopharyngodon idella* (Grass carp). (ii) **Minor Carps.** They are smaller in size and their growth rate is slower, *e.g., Labeo bata.*

Cat Fishes. They do not have scales but have well developed barbels. Teeth are mostly well developed. They are carnivorous, *e.g., Mystus seenghala, Clarias batrachus* (Magur), *Heteropneustes fossilis* (Singhi), *Wallago attu* (Fresh Water Shark), *Rita rita.*\

Murrels (Snake-headed fishes— They have snake-like head). Scales are present both on body and head. They are carnivorous, *e.g., Ophiocephalus* (= *Channa*) *punctatus.*

Live fingerlings (2″ size) of *Channa* species are used in Hyderabad once every year (in June) to cure asthma free of cost. The mouth of fingerling is filled with some herb and the patient is made to swallow it. However, no scientific explanation of this fish therapy is known.

***Labeo rohita* (Rohu).** It is found in clear and sluggish rivers and streams. The adults are chiefly **herbivorous** in diet. The young ones are **planktivorous**. Two short thread like structures, the **barbels,** are present. The tail is **homocercal.** This fish serves as a popular delicious dish.

Catla catla (Theila). It is a fresh water fish inhabiting all the rivers in India. It feeds on plankton and decayed vegetables. The trunk and tail bear moderate sized scales. Barbels are absent. *Catla catla* is an excellent food fish.

***Anabas*— The Climbing Perch.** It can live out of water for some time, where it respires through **accessory respiratory organs** lying in front of the gills. It is carnivorous predatory fish. It is very fond of eating earthworms. It is unable to climb trees. Birds may pick it up from land and drop on trees. This has led to its common name— climbing perch. The climbing perch is a good food fish.

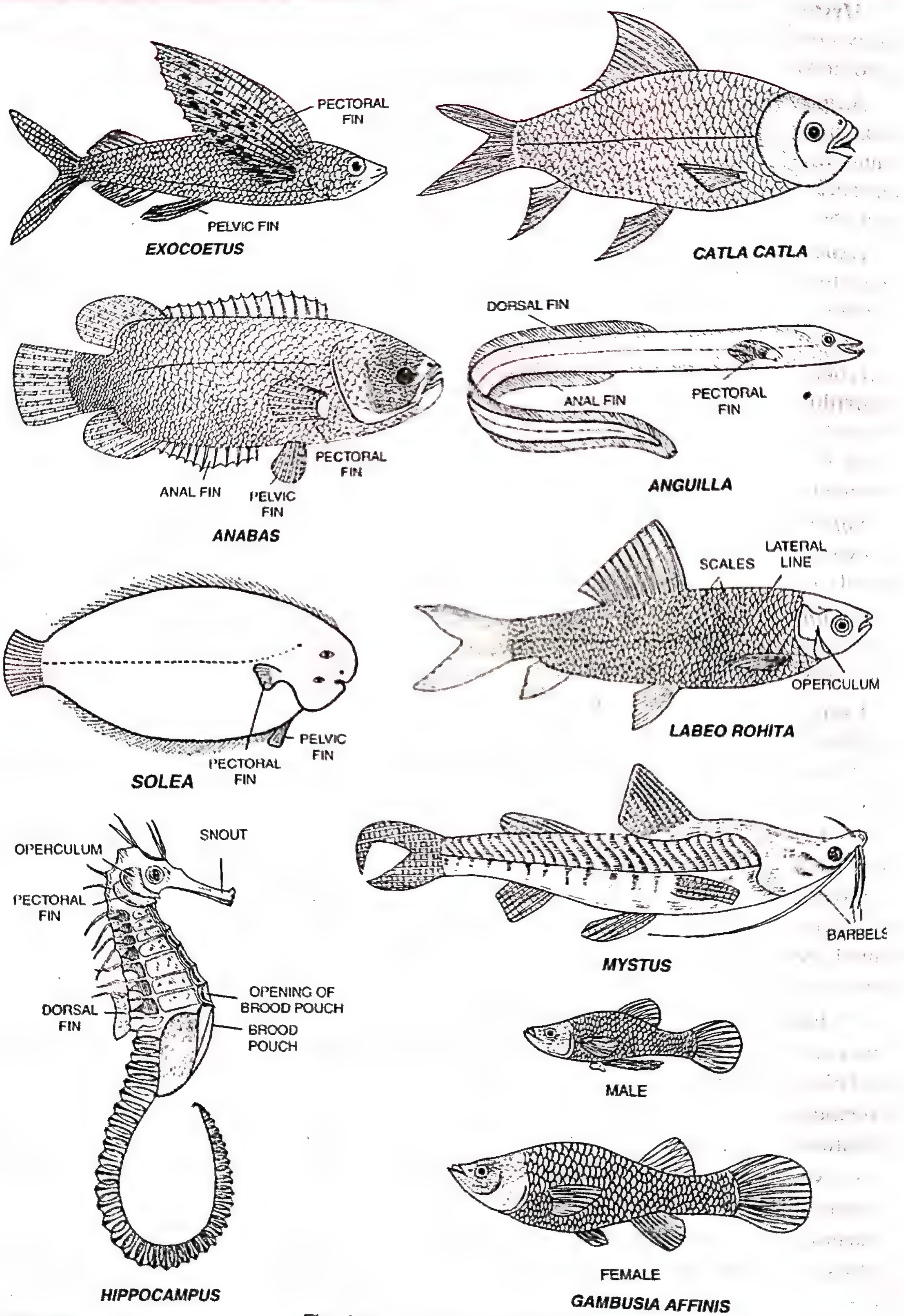


Fig. 4.49. Some Bony Fishes.

***Mystus*— The cat fish.** *Mystus seenghala* is a common fresh water cat fish. It is carnivorous predatory fish feeding exclusively on small fishes, fish fry and prawns. Elongated body is *without scales*. The snout bears *four pairs* of barbels. This fish is also eaten.

***Anguilla* (Fresh water eel).** It has a long snake like body. Skin has rudimentary scales. Adult male and female fishes migrate from river to sea where they lay eggs and die. The young which hatches from egg is called **leptocephalus** (larva of eel). The larvae are so transparent that they are called *glass fishes*. They feed and grow in sea for 2 or 3 years, then enter the river and undergo metamorphosis to become adults.

***Exocoetus* (Flying Fish).** In fact, it does not fly but often leaps into the air upto about six metres high. It is an excellent food fish. The pectoral fins are modified into wing-like structures, with the help of which the fish glides.

***Hippocampus* (Sea Horse).** The neck and the head of the fish are horse-like and the tail is **prehensile**. The fish always swims upright in sea water. The sea-horse exhibits **sexual dimorphism**. The male bears a **brood pouch** in which the female lays eggs and the latter remain there till they hatch. Thus, the parental care is performed by the male. The pelvic and caudal fins are absent. The dried skin of the sea horse is used for the preparation of some ornaments.

***Solea* (Flat-fish).** It is interesting to note that in the early development of the embryo, the eyes of these fishes are laterally situated but being a bottom dweller they are shifted towards one side, as an adaptation to water pressure.

***Gambusia affinis* (Mosquito fish).** It feeds on the mosquito larvae, therefore, it is widely used to control mosquito larvae. *Gambusia* is also called larvicidal fish. It is a fresh water fish and shows sexual dimorphism.

Fig. 4.50. Present distribution of lung fishes.

Lung fishes. There are three genera of living lung fishes: *Neoceratodus, Lepidosiren* and *Protopterus*. All have three chambered heart (two auricles and one ventricle).

1. ***Lepidosiren* (South American Lung Fish)**. It is found in river **Amazon** and **Paraguay** basin in south America. Gills are weakly developed. Respiration is supplemented with two lungs. It undergoes aestivation during summer season.

2. ***Protopterus* (African Lung Fish).** It lives in rivers and large lakes of tropical Africa. Gills are weakly developed. Respiration is supplemented with two lungs. It also undergoes aestivation.

3. ***Neoceratodus* (Australian Lung Fish).** It is found only in the **Burnett** and **Mary** rivers of Queensland in Australia. It respires exclusively by gills and uses its single lung only under stress.

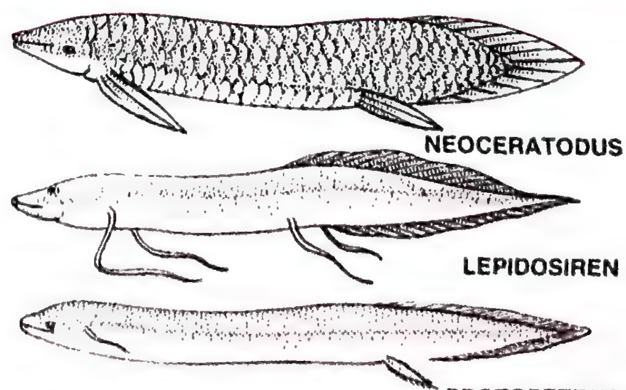


Fig. 4.51. Lung fishes.

***Latimeria* (Coelacanth).** It is a "living fossil" which was taken off from the eastern coast of South Africa, on December 22, 1938 by some

fishermen. Fishermen brought the specimen to Miss Courtenary Latimer, Curator of the local museum. When she failed to identify it, she sent its sketch to Professor J.L.B. Smith, an eminent Ichthyologist of Rhodes University College at Grahams town. He recognised it as surviving member of Crossopterygii (subclass of class Osteichthyes) and named it *Latimeria chalumnii* after the discoverer and locality. Its discovery is of special interest, because it is believed that crossopterygians (fleshy finned fish) were the ancestors of the first amphibians. *Latimeria is believed to be the oldest amongst living fishes.* (Now this fish is not alive). *It is a connecting link between fishes and amphibians.*

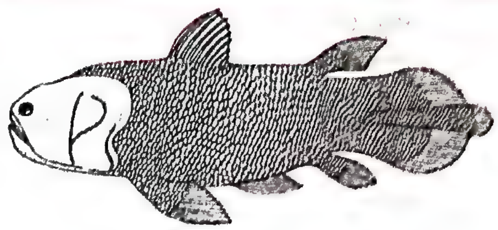


Fig. 4.52. *Latimeria.*

Differences between Cartilaginous and Bony fishes

	Characteristics	*Cartilaginous fishes*	*Bony fishes*
1.	*Habitat*	Mostly marine	Marine and fresh water.
2.	*Mouth*	Ventral	Anterior
3.	*External nares*	Ventral	Dorsal
4.	*Scales*	Placoid	Genoid, Cycloid and Ctenoid
5.	*Operculum*	Absent except *Chimaera*	Present
6.	*Caudal fin*	Heterocercal (asymmetrical).	Usually homocercal (symmetrical)
7.	*Cloaca*	Present except *Chimaera.*	Absent
8.	*Endoskeleton*	Cartilaginous	Partly or wholly bony
9.	*Sprial valve (Scroll valve)*	Present in the intestine	Usually absent in intestine.
10.	*Gills*	5-7 pairs	4 pairs
11.	Swimbladder (air bladder)	Absent	Present
12.	*Excretory matter*	Urea	Ammonia

ADDITIONAL INFORMATION

- **Common Food Fishes of India**

  Fresh Water Food Fishes

  1. *Labeo rohita* (Rohu)
  2. *Labeo calbasu* (Calbasu)
  3. *Catla catla* (Katla)
  4. *Cirrihina mrigala* (Mrigal)
  5. *Mystus seenghala* (Singhara)
  6. *Wallago attu* (Malhi)
  7. *Notopterus chitala* (Chital)
  8. *Ophiocephalus striatus* (Daula)
  9. *Cyprinus carpio* (Common Carp)
  10. *Heteropneustes*
  11. *Clarias batrachus* (Magur)

  Marine Water Food Fishes

  1. *Stromateus* (Pomfret)
  2. *Harpodon* (Bombay Duck)
  3. *Sardinella* (Salmon)
  4. *Hilsa* (Hilsa)
  5. *Anguilla* (Eel)

- *Hilsa* is the only Indian fish that migrates from the sea to the river for breeding. It migrates from the Bay of Bengal to the Ganges, Brahmaputra, Godavari and Krishna. Dr. Hora studied the migration of Hilsa. Hilsa is the national fish of Bangladesh.
- **Largest fish**— The whale shark, upto 18 m long, weighs over 40 tonnes. **Smallest fish**— Pygmy goby, up to 11 mm long, weight 4- 5 mg. **Fastest fish**— Sail fish, about 109 km/h.
- **Ichthyology**— the study of fishes.
- **Torpedology**— study of skates and rays.
- **Pisciculture**— culture of fishes.
- Origin of jawless fish— **Ordovician period.**
- Origin of jawed fish— **Silurian period.**
- **Devonian Period**— "Age of fishes".
- Most primitive fish (fossil): *Climatius.*
- Most beautiful fish in the sea: **Zebra fish.**
- Most poisonous fish: **Stone fish.**
- **Most Advanced Fishes.** Lung Fishes.

- **Most Powerful Electric Fish.** *Torpedo*
- **Bombay Duck** is a bony fish.
- **Seabass** (*Diploprion*) is hermaphrodite (bisexual) fish.
- **Catadromous fish migration.** When fishes migrate from the estuaries to the sea for breeding, it is called **catadromous migration**, *e.g.*, *Anguilla*.
- **Anadromous fish migration.** When fishes migrate from sea to the estuaries, *e.g.*, *Hilsa*.
- **Pomfrets** are the most popular edible fish in India. They are marine.
- Female *Tilapia* fish takes the fertilized eggs and very small young ones into her buccal cavity in time of danger.
- **Types of Scales in Fishes: 1. Cosmoid scales.** They occurred in extinct lobed finned fishes. These scales are now found in lung fishes.

  2. Placoid Scales. These scales are found in cartilaginous fishes, *e.g.*, *Scoliodon*.

  3. Ganoid Scales. These scales are found in primitive bony fishes, *e.g.*, *Polypterus*, *Acipencer*.

  4. Cycloid Scales. These scales have circular ridges. The cycloid scales are found in higher bony fishes, *e.g.*, Carps, lung fishes.

  5. Ctenoid Scales. They are comb-like. Ctenoid scales are found in higher bony fishes, *e.g.*, Perch.
- **Dipnoi** (Gr. *di* = two, + *pneoe* = breathing)- means double breathers as they respire through gills as well as lungs. Dipnoi is a group of bony fishes which includes lung fishes.
- **Exotic Fishes.** The fishes introduced from other countries, *e.g.*, *Cyprinus carpio*, *Ctenopharyngodon idella* (Grass carp), *Gambusia affinis*, *Tilapia mossambica*, *Salmo salar* (Atlantic Salmon).
- **Fry.** A stage of very young fish when mouth is open for feeding and yolk present though diminishing fast.
- **Fingerling.** A stage beyond advanced fry to a size of 5 inches in length.
- **Weberian Ossicles.** Named after the name of their discoverer (**Weber**, 1820). In certain fishes (*e.g.*, *Labeo*), a chain of four small bones (*Claustrum*, *Scaphium*, *Intercalarium and Tripus*) connects the air bladder and internal ear on either side. They are considered helpful in hearing.
- Rohu does not have stomach.
- **Isinglass** is a product made from swim bladder of fishes containing 90% gelatin.
- **False fishes** (which do not belong to Pisces)

  (a) **Jelly fish** : *Aurelia* — a scyphozoan from Coelenterata.

  (b) **Cray fish** : *Astacus* — a crustacean from Arthropoda

  (c) **Silver fish** : *Lepisma* — an insect from Arthropoda.

  (d) **Razor fish** : *Solen* — a bivalve from Mollusca.

  (e) **Cuttle fish** : *Sepia* — a cephalopod from Mollusca.

  (f) **Devil fish** : *Octopus* — a cephalopod from Mollusca.

  (g) **Star fish** : *Asterias* — an asteroid from Echinodermata.

  (h) **Hagfish** : *Myxine* — a cyclostomate from Agnatha.

  (i) **Whale fish** : *Orcinus* — a cetacean from Mammalia.
- **'Mermaid purse'** refers to the egg capsule of sharks and skates.
- **The common** skates (***Raja, Raia***) when viewed from above they look like kites with a sharp tail.
- In *Echeneis* **(Sucker fish)** sucker represents modified anterior dorsal fin.
- **Mahseers** are found in hill streams and upper reaches of rivers in the northern latitudes.
- The so-called **'live fishes'** have accessory respiratory organs which enable them to survive out of water for a relatively long time. Examples, *Clarias batrachus*, *Heteropneustes fossilis*, *Channa striatus*, *Channa punctatus* & *Anabas testudineus*.
- Even today, people of Japan, the Philippines and other islands in the Pacific ocean eat raw fish.
- Fishes are rich in protein and minerals like calcium, phosphorous and iron. Some fishes in addition have varying quantities of fats.
- Fisheries includes (1) Marine (i) Coastal (ii) Offshore & Deep sea. (2) Inland (i) Estuarine (ii) Riverine (iii) Pond culture.
- *Lophius* **(Angler Fish).** First spine or ray on head with a fleshy mass or bait at tip (called **illicium**) is to lure prey into mouth. Small skin flaps fringing the body mimic leaves of aquatic plants. *Lophius* shows sexual dimorphism.

Class Amphibia— The Vertebrates with Dual-life

(Gk. *Amphi*– two or both; *bios*– life)

General Characters

1. They are the first cold blooded vertebrates from evolution point of view which came to the land. Class Amphibia includes about 3,000 species.

2. They are **amphibious** in nature, *i.e.*, they can live on land as well as in water. They are mostly found in warm countries. They are ectothermic (cold blooded).

3. Body is divisible into **head** and **trunk**. Tail may be present in some amphibians.

4. The skin is smooth or rough having glands which keep it moist.

5. They are usually without scales, but if present they are hidden beneath the skin (*e.g.*, **caecilians**).

6. Paired fins are absent. Unpaired fins may be present. Two pairs of limbs are used for locomotion except caecilions.

7. The gills are present at least in the larval stage; some adult forms also carry external gills in addition to lungs (*e.g.*, *Necturus, Proteus*).

8. Skull is **dicondylic**, *i.e.*, with two occipital condyles for articulation with vertebral column.

9. The respiratory organs are lungs, buccopharyngeal cavity, skin and gills.

10. The heart is three chambered, having two auricles and one ventricle. In the heart, there are present sinus venosus and truncus arteriosus. Both hepatic portal and renal portal systems are well developed. RBCs are biconvex, oval and nucleated.

11. Kidneys are mesonephric. Urinary bladder is present in frog. Larvae and tailed amphibians (*e.g.*, salamanders) are ammonotelic. Frogs and toads are ureotelic.

12. Alimentary canal, urinary and reproductive tracts open into a common chamber called **cloaca** which opens outside through **cloacal aperture**.

13. Ear consists of internal and middle ear. **Tympanum** (outer membrane) covers the middle ear. The eyes have eyelids. Nictitating membrane is well developed.

14. Ten pairs of cranial nerves are present.

15. Lateral line system is found during their development.

16. Fertilisation is external. However in *Salamander* and *Ichthyophis* (blind worm) fertilisation is internal. They are mostly oviparous, however, *Salamandra salamandra* is viviparous. Development is mostly indirect.

17. They return to water for breeding. Male lacks copulatory organs. The metamorphosis is usually present. A fish like larva, the **tadpole** is present.

18. They occur in fresh water and moist land. *Amphibians are not found in sea water except a few.*

Classification. Living Amphibians are divided into three orders :

Order 1. Apoda (Gymnophiona or Caecilia). Limbless, scales present, *e.g.*, *Uraeotyphlus, Ichthyophis*. They are called **"blind worms"** or **caecilians**.

Order 2. Urodela (Caudata). Tail present, *e.g.*, *Necturus* (Mud puppy), *Amphiuma* (Congo-eel), *Salamandra, Proteus, Siren* (Mud-eel), *Ambystoma, Triturus* (newt).

Order 3. Anura (Salientia). Without tail, *e.g.*, *Rana* (Common frog), *Rhacophorus*, *Bufo*, *Hyla*, *Alytes*, *Xenopus* (African toad), *Pipa*.

***Ichthyophis* (Blind worm).** It is limbless. Dermal scales are embedded in the skin. Male copulates with female by a protrusible cloaca and thus fertilization is internal. The female shows parental care by carefully coiling her body around the eggs till they hatch.

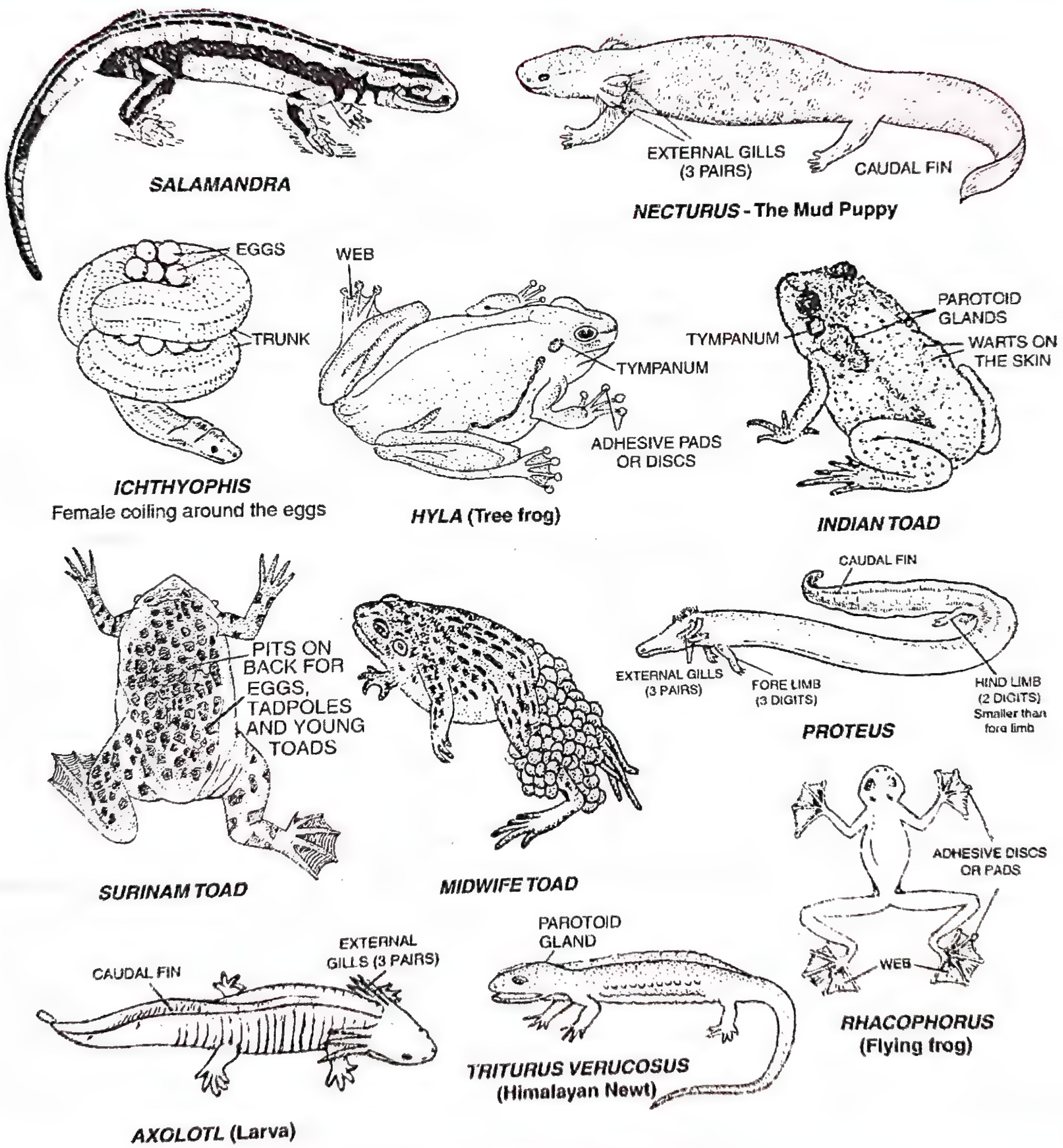


Fig. 4.53. Some Amphibians.

***Necturus* — Mud Puppy, Water Dog.** Eyes are without eye-lids. Tympanum is absent. There are three pairs of external gills. Tail bears caudal fin which is without fin rays. It is nocturnal.

Axolotl. The larva of *Ambystoma* (**tiger salamander**) is known as **Axolotl**. It has three pairs of external gills and a tail having a caudal fin. It exhibits the phenomenon of **neoteny**. When there is iodine deficiency in water, the Axolotl does not change into an adult, but remains in the larval form and becomes sexually mature to start sexual reproduction. Axolotl is found in mountain regions of Mexico.

Proteus (European blind cave salamander). The broad head has rudimentary eyes, so that it is blind. Three pairs of external gills, laterally flattened tail with a caudal fin and weak fore and hind limbs are present. Fore-limbs have three digits and hind limbs have two digits. Hind limbs are smaller than the fore limbs.

Salamandra **(Salamander).** *Salamandra* (European spotted or fire salamander). The male discharges sperms in capsule called spermatophore which is picked up by the female with cloacal lip to fertilize her eggs (ova) internally. It is **viviparous.** Gills are absent in the adults. The trunk bears fore and hind limbs with four fingers and five toes respectively.

Triturus verrucosus (formerly described as *Tylototriton verrucosus*). It is also called **Himalayan newt** because it lives in the Eastern Himalayas. In India, it is found in the Darjeeling Hills, Meghalaya, Sikkim, Manipur and Arunachal Pradesh. Head is with rounded snout and a pair of **parotoid glands**. Arms and legs are equal in size. It is nocturnal, carnivorous and possesses very good power of regeneration. It hibernates in winter.

Pipa **(The Surinam toad).** It is famous for the unique method of parental care. The female surinam toad carries the tadpoles in special pits on its back till tadpoles become toads.

Alytes **(The mid-wife toad).** Male shows parental care. The male mid-wife toad carries the eggs around his thighs and stays in damp places until tadpoles hatch to enter water.

Hyla arborea **(Tree frog).** It is adapted for life in trees. Large vocal sacs help in making a very loud voice. *Hyla faber* shows parental care by making enclosures in shallows water on the border of the pond for protection.

Rhacophorus **(Flying frog).** The limbs are thin and long with well developed webs between the digits. It lives in trees and glides from tree to tree or from tree to the ground. It also exhibits parental care by depositing eggs in the nest near water.

Bufo melanostictus **(Indian toad).** It inhabits on land in moist and dark shady places, such as the corners of gardens and under the leaves and stones, etc. It is a terrestrial and **nocturnal** animal. The secretion of its skin glands contains **bufonin** and **bufotalin**, which probably have healing property. For breeding it goes to water where it lays eggs in strings. Since it bears poisonous glands (**parotoid glands**), it is not generally eaten by other animals like snakes, birds, etc.

Rana tigrina (Indian Bull-Frog). It has been described in detail in Chapter 7A "Structural Organisation in Animals".

Differences between Frog and Toad

Frog	*Toad*
1. Frog mostly lives in water but comes to land for feeding.	1. Toad lives on land and comes to water for breeding.
2. Frog is diurnal.	2. Toad is nocturnal.
3. Frog lays eggs in a mass.	3. Toad lays eggs in a line.
4. Head is triangular.	4. Head is semicircular.
5. Body is olive-brown with dark spots.	5. Body is brownish grey.

6. Skin is moist and smooth. It has numerous mucous glands and fewer poisonous glands.	6. Skin is dry and rough. It has numerous poisonous glands and fewer mucous glands.
7. Frog does not have parotoid glands.	7. Toad has a pair of parotoid glands.
8. Toes of frog have well developed webs.	8. Webs are not developed.

ADDITIONAL INFORMATION

- At the time of metamorphosis the tadpole does not feed.
- **Largest amphibians.** Japanese Giant Salamander which grows to a length of 1.6 m. **Smallest amphibian.** One of the South American Arrow Poison Frogs, which measures upto 1.3 cm. The poison of its skin can cause instant death.
- Amphibians originated in **Devonian Period.**
- **Carboniferous Period**— "Age of Amphibians".
- **Longest Gestation Period.** In ovoviviparous *Salamandra atra* (36 months).
- **Most poisonous Frog. Golden dart poison frog** from South America. One adult frog contains enough poison to kill 2200 people. Skin secretes, powerful poison.
- Salamanders are better adapted to life on land than newts. Salamanders' lives are similar to those of newts, except that they usually live in warmer areas and do not need to hibernate.

Class Reptilia—The Creeping Vertebrates

(L. *Reptare*– to creep)

General Characters

1. Reptiles are the creeping and burrowing cold blooded vertebrates bearing epidermal scales. They are ectothermic (cold-blooded) and are found mostly in the warmer parts of the world. They are few in colder parts. They are mostly terrestrial animals. There are about 6,000 living species of reptiles in the world.

2. Skin is dry, rough and without glands, bearing epidermal **scales** or **scutes.**

3. Snakes and lizards shed their scales as skin cast.

4. They do not respire by means of gills. Respiration always takes place through lungs. Ribs help to expand and contract the body cavity, making the lung respiration more efficient than in amphibia.

5. Skull is **monocondylic,** *i.e.*,with single occipital condyle.

6. Except in snakes, there are two pairs of pentadactyl limbs, each with 5 digits bearing claws— tetrapodus pentadactyl type.

7. Heart consists of two auricles and a partially divided ventricle. In crocodilians, heart is four chambered (two auricles and two ventricles). Renal portal system is less developed. RBCs are nucleated.

8. Kidneys are **metanephric.** Urinary bladder may be present. Crocodiles are ammonotelic. Turtles and alligators are ureotelic. Lizards and snakes are uricotelic.

9. Twelve pairs of cranial nerves are present.

10. Each ear consists of three parts; external, (if present, is poorly developed), middle and internal. Snakes do not possess ears.

11. The lateral line system is altogether absent.

12. Tortoises feed almost entirely on vegetation. Some turtles are flesh eaters. All other reptiles are carnivorous/insectivorous.

13. A typical cloaca is present.

14. They are mostly oviparous. Reptiles lay **macrolecithal eggs (= polylecithal eggs).** Some forms are ovoviviparous or viviparous. Embryonic membranes (chorion, amnion, allantois and yolk sac) are formed during development.

Classification

Living Reptiles are divided as follows: **Subclass 1. Anapsida:** Skull has a solid bony roof; no temporal vacuities. It includes only single living **order chelonia** *e.g., Chelone* (turtle), *Testudo* (Tortoise), *Trionyx* (Terrapin)—soft shelled turtle of Indian rivers. **Sub class 2. Diapsida:** Skull has two temporal vacuities. It includes three living orders. **Order 1 Rhynchocephalia** *e.g., Sphenodon* (Tuatara)—a living fossil. **Order 2 Squamata.** It includes two suborders: (i) **Suborder Lacertilia (Sauria)** *e.g.*, Lizards, such as *Chameleon* (Tree lizard), *Calotes* (Garden lizard), *Hemidactylus* (wall lizard). (ii) **Suborder Ophidia** *e.g.*, snakes, such as *Naja* (Cobra), *Bungarus* (Krait), *Vipera* (Viper). **Order 3. Crocodilia** *e.g., Crocodilus* (Crocodile), *Alligator, Gavialis* ("Gharial"). They have (i) thecodont teeth, (ii) lungs in pleural cavities, (iii) a muscular diaphragm, analogous to that of mammals and (iv) 4-chambered heart.

Following extinct groups of class reptilia are important to mention here.

- **Cotylosauria.** They were most primitive reptiles and closest to early amphibians. They were without temporal fossae in the skull, *e.g., Seymouria.*
- **Ichthyopterygia.** They were fish-like and had single fossa in the skull, *e.g., Ichthyosaurus.*
- **Archosauria.** They had diapsid skulls. Some were bipedal and gave rise to birds. A group of Archosauria also gave rise to dinosaurs, *e.g., Brontosaurus.*
- **Synaptosauria.** The skull had a single temporal fossa on either side. They were mammal–like reptiles that later on gave rise to mammals, *e.g., Plesiosaurus.*

Dinosaurs (Ancient Reptiles)

The word 'dinosaur' is a blend of the Greek terms 'deinos' (meaning terrible) and 'saurus' (meaning lizard). **Richard Owen** coined the term dinosaur. The dinosaurs were divided into two main types; one with a bird like pelvis and the other with reptilian pelvis.

Fig. 4.54. *Dinosaurs.*

A. **Reptile-like Dinosaurs (Saurischia).** The early dinosaurs of this group were fast, carnivorous, two legged forms. *Tyrannosaurus* is an example of gigantic carnivorous dino-

saurs. It was about 15 mts long. Many saurischia changed to a plant diet and became four legged forms. *Brontosaurus*. the biggest of them was with an estimated weight of 50 tons.

B. **Bird-like Dinosaurs (Ornithischia).** The dinosaurs of this group were herbivorous. Although, some of them walked upright, the majority were four-legged. Having lost their front teeth, they developed a stout, horny, bird-like beak. *Ankylosaurus* is an important example of this group.

Pteranodon was flying dinosaur.

Embryonic Membranes

During development, in reptiles, birds and mammals, embryo forms four membranes called embryonic membranes. These are **chorion**, **amnion**, **allantois** and **yolk sac**. Due to their occurrence, reptiles, birds and mammals are called **amniotes.** Fishes and amphibians do not have these membranes, hence they are called **anamniotes.**

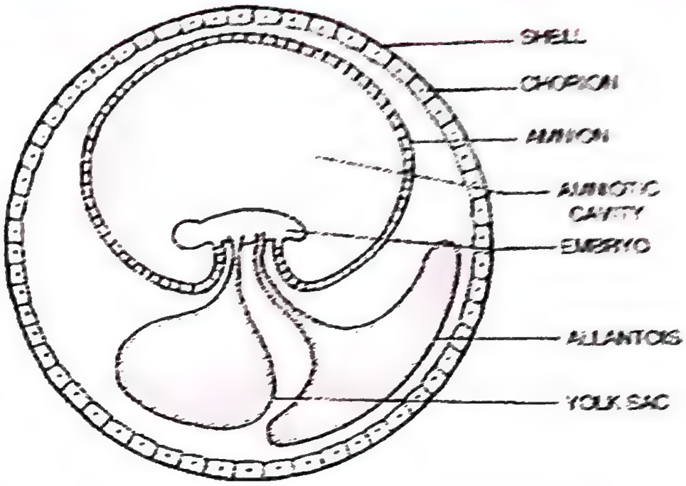


Fig. 4.55. Diagram showing embryo and four embryonic membranes.

Reasons for success of reptiles on land

Four features make reptiles true land animals. (i) Internal fertilization. (ii) The amnion (embryonic membrane) encloses the embryo and provides it with a watery environment during development, therefore, embryo does not need watery environment (iii) Shell around egg to check desiccation. (iv) Horny scales on body of reptiles check loss of water.

Living Reptiles

Testudo (Tortoises) and Chelone (Turtle). The body is protected by a **shell** consisting of a dorsal **carapace** and ventral **plastron.** They are toothless. Both tortoises and turtles feed on vegetation but some turtles are flesh eaters. **Giant tortoises** weigh upto 600 kg. They are considered the **longest living animals** (more than 180 years).

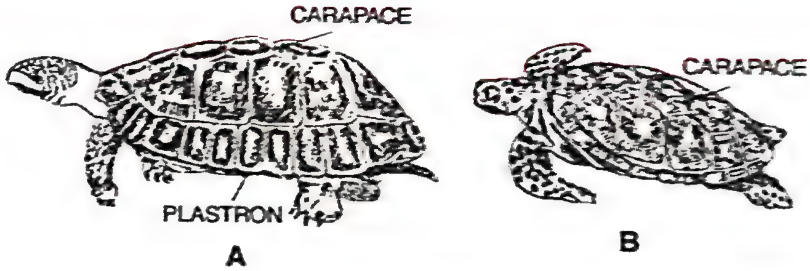


Fig. 4.56. A, Testudo (Tortoise) ; B, Chelone (Turtle).

Differences between Tortoise and Turtle

Tortoise (Testudo)	*Turtle (Chelone)*
1. It is a semi-terrestrial form.	1. It is an aquatic form.
2. Tortoise bears somewhat ovoid carapace.	2. Turtle has heart shaped carapace.
3. Fore and hind limbs are not modified into paddles.	3. Fore and hind limbs are modified into paddles.
4. Head and neck can be completely withdrawn into the shell.	4. Head is partially withdrawn into the shell.
5. Tortoises feed almost entirely on vegetation.	5. Some turtles are flesh eaters.

Terrapins (Freshwater Tortoises). They are hard-shelled forms which closely resemble land tortoises in appearance. They are herbivorous but omnivorous forms are also found. The majority of the terrapins occur in large rivers like the Ganga. Many are semi-terrestrial.

***Sphenodon* (Tuatara).** It is burowing carnivorous and nocturnal in habits. It is lizard like and is about 70 cms long. The young tuatara has a rudimentary third eye on the top of the head. It was formerly found throughout New Zealand but now it is restricted to some small neighbouring islands. The "living fossil" is strongly protected under law by the Government of New Zealand.

Fig. 4.57. *Sphenodon.*

Lizards (Fig. 4.58)

Heloderma. There are only two types of *poisonous lizards* in the world — the **gila monster** (*Heloderma suspectum*) and the **beaded lizard** (*Heloderma horridum*), both found in parts of the U.S.A and Mexico. In these two types of lizards, the venom glands and "fangs" are in the lower jaw. The venom flows out of four pairs of grooved lower teeth.

***Draco*— Flying lizard (Flying dragon).** It has membranous parachute-like folds of skin, the **patagia** (Sing. patagium) supported by extended ribs. The patagia are used for gliding from tree to tree. *Draco* is common in India (Assam, Kerala), Myanmar (Burma) and Malaysia.

Glass Snake. It is a **limbless lizard.** It derives its name (glass snake) from its ability to break off its tail when seized. *Ophiosaurus gracilis* is North Indian glass snake. *Barkudia* is South Indian glass snake. *Auguis fragilus* is European glass snake.

***Chameleon* (Tree Lizard).** Chameleons have arboreal life. It has long tongue used for catching the prey. Its tail is long and prehensile. Chameleon has the ability to change the colour of its body according to the surrounding.

***Phrynosoma* — Horned toad.** It is spiny lizard of USA and Mexico. It shows desert adaptation hence also called **desert lizard.**

***Varanus*— Monitor lizard ('Goh').** Its tongue is long and protrusible. *Varanus komodoensis* **(Komodo dragon)** found in eastern islands of Indonesia, is the **largest living lizard** in the world. It may reach a length of 3 metres and weights 250 kilos.

***Hemidactylus*— Wall lizard or Gecko.** It exhibits the phenomenon of **autotomy** (voluntary casting off a part of the body when the animal is attacked). It breaks off its tail to escape from the enemy. Later on the tail regenerates. It is **nocturnal.** Each finger and toe dilates into two rows of **ridged lamellae** to form **adhesive pads** on the ventral surface. These pads work on vacuum cup principle and, thus, help animal to move on ceiling and smooth surfaces. The wall lizard checks insects population. It is not poisonous.

***Calotes*— The Garden lizard ('Girgit').** It is arboreal. When excited, head and neck turn red and trunk becomes pale yellow. Male performs a peculiar courtship dance before the female.

***Uromastix*— The spiny-tailed lizard.** It is called "Sanda" in Hindi. Oil is extracted from its fat bodies. This oil is used for the treatment of muscular pain..

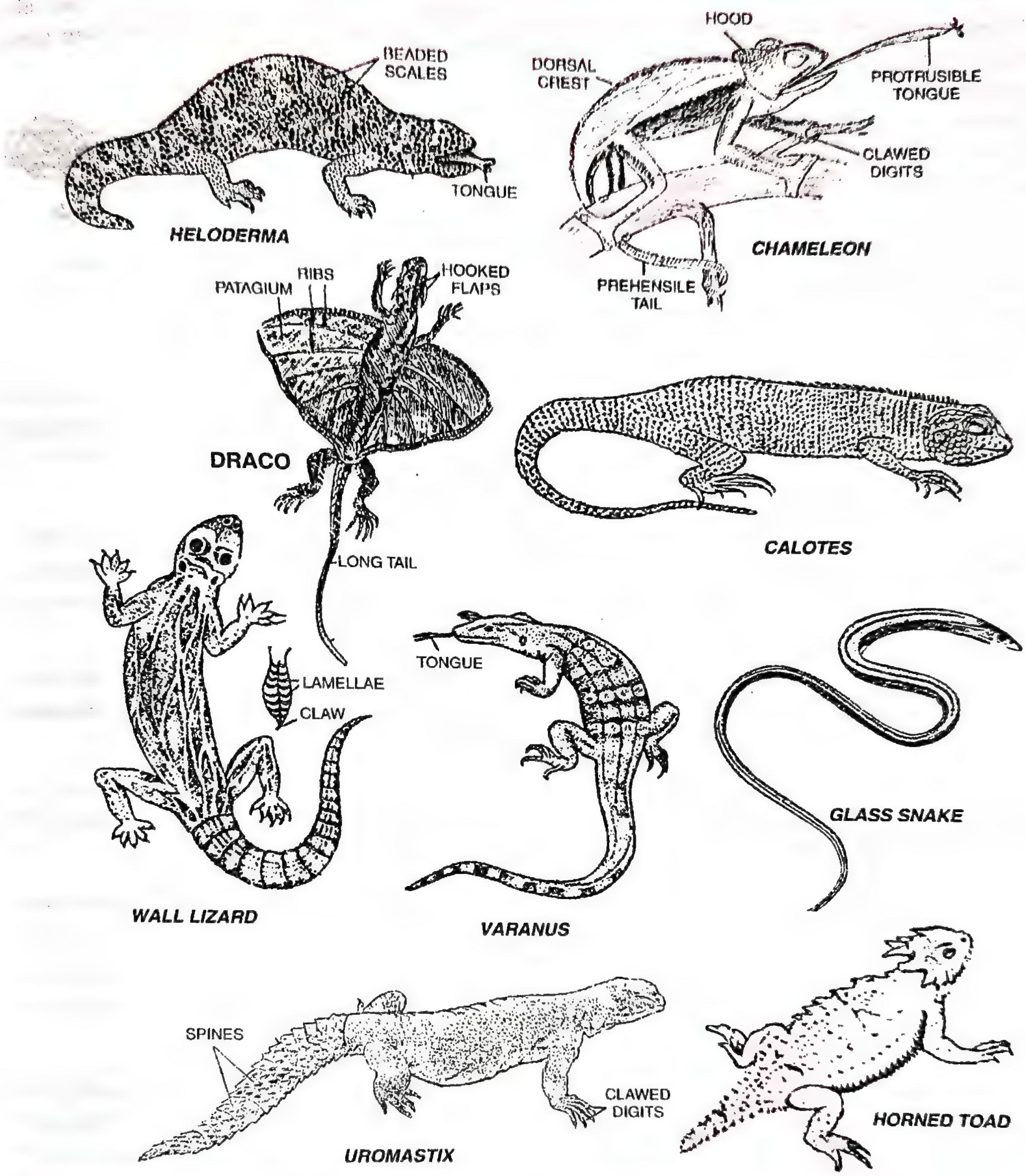


Fig. 4.58. Some Lizards.

Differences between Salamander and Lizard

Salamander	*Lizard*
1. It is amphibious.	1. It is terrestrial.
2. Claws are absent in fingers and toes.	2. Fingers and toes have claws.
3. Ear openings are absent.	3. Ear openings are present.

Snakes

A typical snake is elongated and devoid of limbs. The body is covered with scales, which are differentiated into shields and plates. The tympanic membrane and tympanic cavity are absent. Apparently, the eye lids are absent but, if present, are immovable. The nictitating membrane is absent. The tongue is long, bifid and protrusible. The sternum is absent. The lungs are asymmetrical, the right one being larger. Urinary bladder is absent. There are no vocal cords, therefore, snakes can only hiss through the nostrils. The locomotion is brought about by the lateral body wall muscles through the movement of the ribs.

The sound waves are picked up by the general body surface from the surrounding earth and conveyed to the brain through a small bone, the **columella**. Both upper and lower jaws bear teeth. In poisonous snakes, a pair of teeth on the upper jaw becomes large and specialised for biting, which are called **fangs**. *Fangs are modified maxillary teeth.* There is present a pair of **poison glands**, each opening at the base of fang of its side by means of a poison duct. *Poison glands are modified salivary glands.* Generally, poisonous snakes leave two fang marks, rarely one if it is a side-bite. Non-poisonous snakes usually produce a row of U-shaped teeth marks. *Ramphotyphlops braminus* (**common worm** or **blind snake**)— a non-poisonous snake reproduces by parthenogenesis. Only female forms are found in this snake.

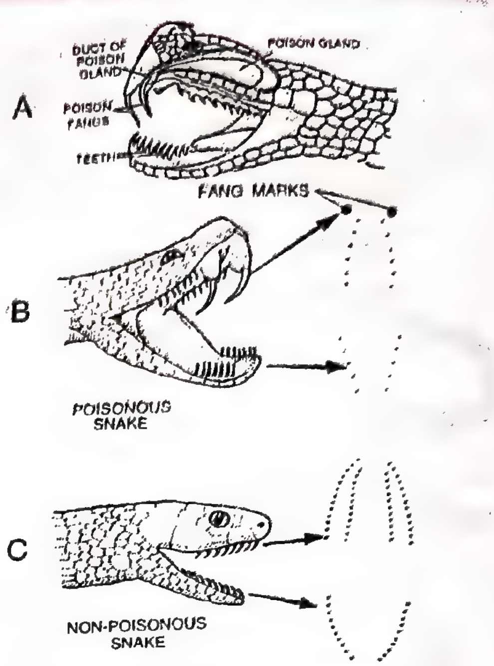


Fig. 4.59. A, Poison apparatus of a poisonous snake; B, Marks of teeth of a poisonous snake; C, Marks of teeth of nonpoisonous snake.

Naja naja **(Indian Cobra).** *Naja* is from the Sanskrit word **Naaga**. It usually lives in rat holes, under stones and thick vegetation, but also comes into human dwellings. *Ophiophagus hannah,* the **King cobra** *is the only snake in the world that builds a nest.* It guards the eggs. Cobras exhibit **cannibalism**, *viz.,* they eat their fellow snakes. Cobras are recognised by the *presence of hood.* The **hood** is formed by the expansion of the neck. *The Third supralabial scale touches the eye.* Cobra is deadly poisonous. However, cobra venom is believed to help in curing cancer.

Bungarus **(Krait).** Sandy soil, termite mounds, burrows of small rodents and piles of brick are the best places to find common kraits. Head is slightly wider than neck and bears large shields. Four Infra labial scales are present in which the *fourth infra labial scale is the largest.* A line of hexagonal scales is found mid dorsally. Kraits are nocturnal and are true cannibals. Their venom is extremely toxic.

Vipera **(Viper).** A viper is viper because it is viviparous. The head is triangular, flat and covered with small scales. Loreal pits between eyes and nostrils are absent in viper, however, **loreal pits** are present between eyes and nostrils in **pit viper**. It has large plates on ventral surface.

Hydrophis (Sea Snake). It is also called **Samudra Sanp** in Hindi. The tail is laterally compressed and is adapted for swimming in water. *Hydrophis* is deadly poisonous.

Python **(Ajgar).** It is a large, huge, massive non-poisonous snake. It may attain the length of 10 metres or more and is thought to be biggest snake of India. It is predaceous and kills the prey by coiling around and crushing and swallowing its prey. Its body is covered

with small scales. *Vestiges of hind limbs and pelvic girdles are present.* Tail is short and prehensile.

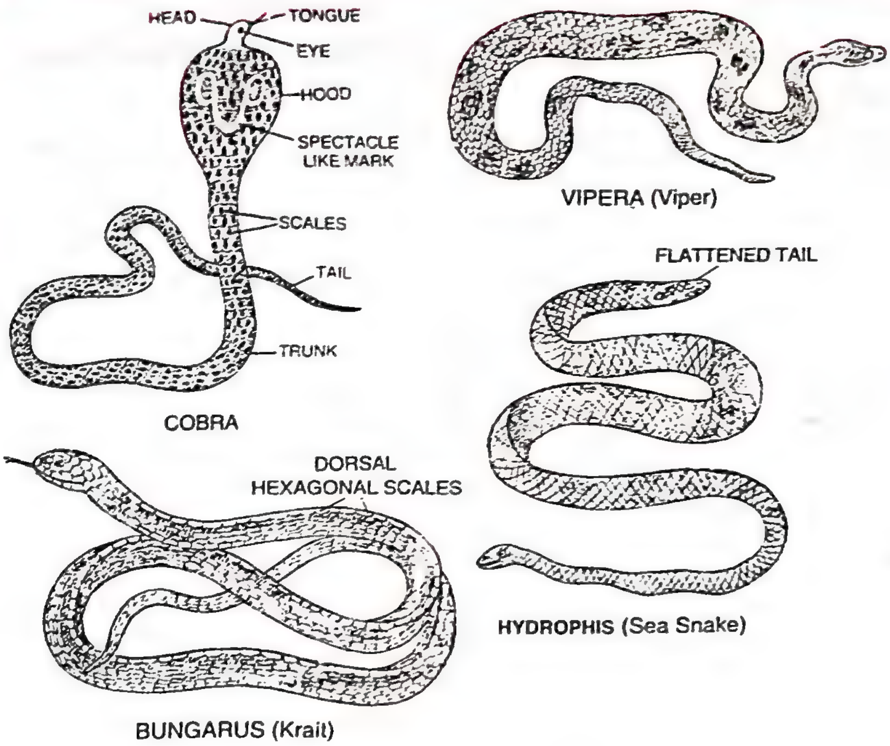


Fig. 4.60. Some poisonous Snakes.

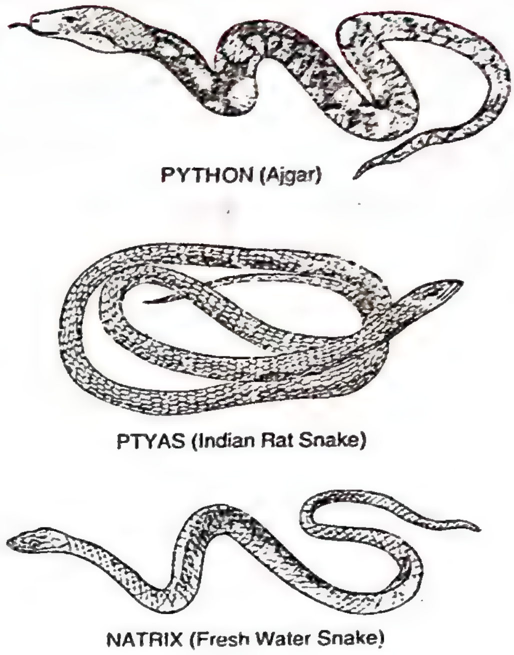


Fig. 4.61. Some non-poisonous snakes.

Differences between Lizards and Snakes	
Lizards	*Snakes*
1. Body has uniform scales.	1. The scales are differentiated into shields and plates.
2. Eyelids are movable. Nictitating membrane is present.	2. Eyelids are absent, if present, are immovable. Nictitating membrane is absent.
3. Ear openings and tympanum are present.	3. Ear openings and tympanum are absent.
4. Both lungs are equally developed (symmetrical).	4. Left lung is greatly reduced.
5. Urinary bladder is present.	5. Urinary bladder is absent.

Identification of Poisonous and Non-poisonous Snakes

Arrangement and size of the scales, plates and shields covering the body help in the identifiction of snakes.

(a) Except one species, all the **sea-snakes** are poisonous and **have flattened tail**. The head of the sea-snakes is covered with large shields. The only non-poisonous species of sea-snakes has small scales over the head and tail is flattened.

(b) The terrestrial snakes have rounded or cylindrical tails. They are non-poisonous and poisonous which can be recognised by following points :

1. If the small scales are present on the belly and back, it is a non-poisonous snake.

2. If the belly scales are not broad enough to extend right across it, it is a non-poisonous snake.

3. If broad plates cover the entire width of the belly, it is poisonous or non-poisonous.

4. If small scales are present on the head, it is poisonous and a **viper.**

5. If small scales or shields are present on the head and a **pit** lies between the eye and the nostril, it is poisonous and a **pit-viper.**

6. If dorsal side of the head has both small scales and large shields, the snake may or may not be poisonous.

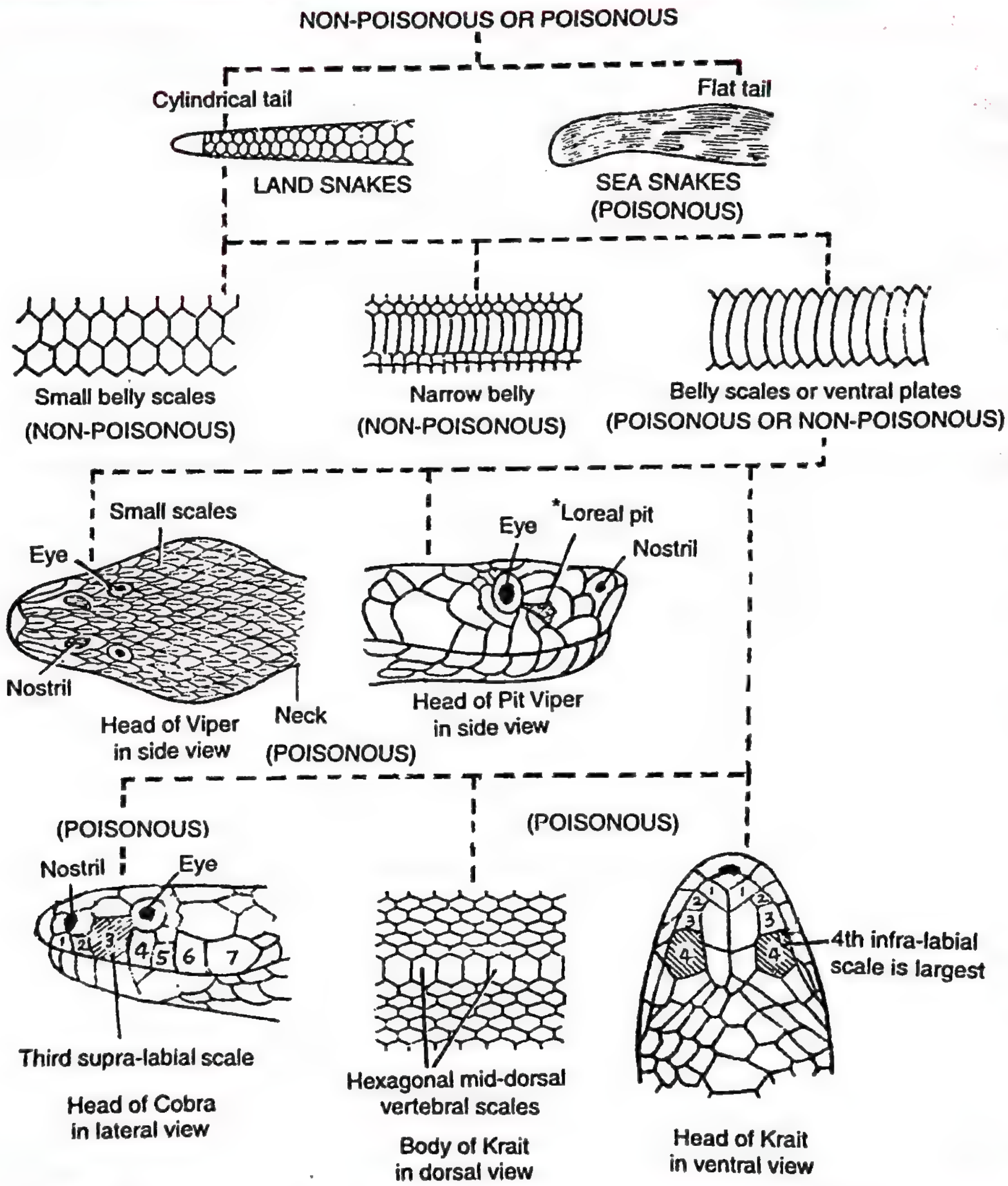


Fig. 4.62. Identification of poisonous and non-poisonous snakes.

7. If the **third supra labial scale** touches the eye and the nostril, the snake is a cobra or a coral snake. If the neck is with hood and markings, it is **cobra.** If neck is without hood and coral spots are present on the belly, it is a **coral snake.** Both cobra and coral snakes are poisonous.

8. If vertebrals (scales on the middle of the back) are hexagonal and larger than other

*Loreal – space between snout and eye.

scales over the back and the **fourth infra-labial scale** is the largest, it is poisonous and a **krait.**

9. If the snake has small scales and large shields on the head but does not have the characters of cobra, coral-snake or krait, then it is non poisonous.

Poisonous Snakes. (1) *Naja naja* (Indian Cobra). (2) *Ophiophagus hannah* (the king cobra). (3) *Bungarus caeruleus* (common krait). (4) *Bungarus fasciatus* (the banded Krait). (5) *Vipera russelli* (the Russell's viper, the largest Indian pitless viper). (6) *Echis carinata* (the saw scaled pitless viper from South India). (7) *Ancistrodon himalayanus* (the brown Himalayan pit viper of India). (8) *Crotalus* (the rattle snake of North America). (9) *Callophis* (coral snake). (10) *Micrurus* (coral snake of USA). (11) *Hydrophis* (sea snake).

Neurotoxic Venom. It acts on nervous system *e.g.,* venom of Cobra, Krait, Sea snake and Coral snake.

Haemolytic Venom. It breaks down red blood corpuscles *e.g.,* venom of Viper.

Non poisonous Snakes. (1) *Python.* (2) *Ramphotyphlops* (common worm or blind snake). (3) *Ptyas* (the rat snake). (4) *Eryx* (Boa, double-headed snake 'Dumuhi'). (5) *Dendrelaphis* (Tree snake). (6) *Tropidonotus* (common pond or grass snake). (7) *Dryophis* (Green whip snake). (8) *Ahaetulla nasuta* (vine snake).

Double headed snake does not have two heads, only tail resembles the head. About 90% of snakes are nonpoisonous. About 10% of snakes are poisonous.

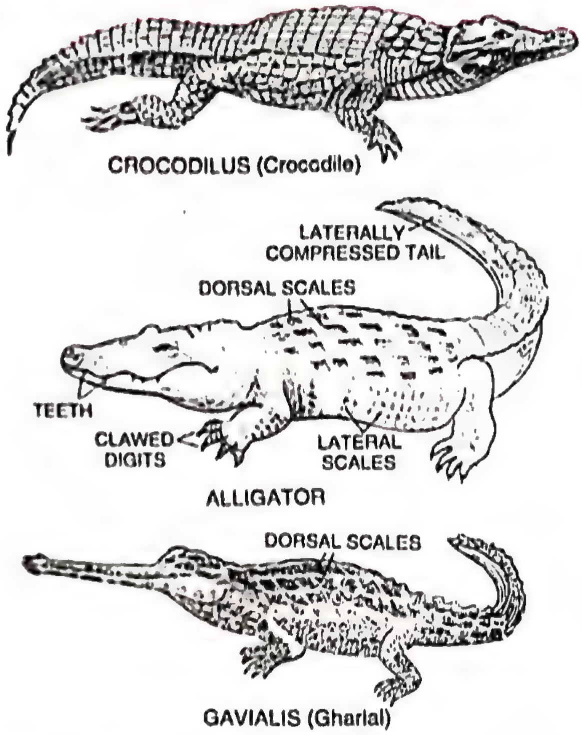


Fig. 4.63. *Crocodilus, Alligator* and *Gavialis.*

Comparison between Crocodile, Alligator and *Gavialis*

Characters	*Crocodilus* (Crocodile)	*Alligator*	*Gavialis* (Gharial)
1. Distribution	Asia, including India, Central America, Africa, Malaya, Indonesia and North Australia.	North America, China.	India. It is also found in Myanmar (Burma) Pakistan and Nepal.
2. Habits	More aggressive, dangerous to man.	Less aggressive, attacks when provoked.	Can eat only fish because of narrow throat.
3. Snout	Moderately long and pointed	Short and broad	Very long
4. Teeth	Unequal	Very unequal	Almost equal.
5. Hump	Such structure does not develop.	Such structure does not develop.	During breeding a hump (ghara-like) develops at the end of snout of male. Hence it is commonly called **gharial.**

ADDITIONAL INFORMATION

- Reptiles without urinary bladder— snakes, crocodiles, alligators.
- **Herpetology**— study of reptiles.
- Rattle snake's tail emits a frightening sound which scares away the enemy.
- Snakes have acute sense of smell. Smell is also perceived by tongue. Snakes have **Jacobson's organs** in the roof of the buccal cavity that help them to detect odours.
- **Most Poisonous Snake**- *Hydrophis* (Sea snake)
- **Longest Poisonous Snake**- King cobra
- **Longest Snake.** Python/Anaconda, may grow upto 10 m in length.
- **Ophiology or Serpentology**— study of snakes.
- Marine iguanas are the only known lizards living in water.
- **Saurology**— study of lizards.
- **Long dinosaur**— *Diplodocus—27 m.*
- **Small dinosaur**— Compsognathus— 75-91 cm.
- **Largest Living Reptiles** (i) Python, (ii) Crocodile (iii) Komodo dragon (a lizard).
- ***Seymouria*.** It was a "connecting link" between amphibians and reptiles.
- ***Lycaenops*.** It was a mammal-like reptile. It is considered a "connecting link" betwen reptiles and mammals.
- ***Pterosauria* (=Pterodactyla).** Their fore limbs evolved into membranous wings. *Rhamphorhynchus* of late Jurassic period was a primitive pterosaur with one metre wing span, a long balancing tail and toothed jaws.

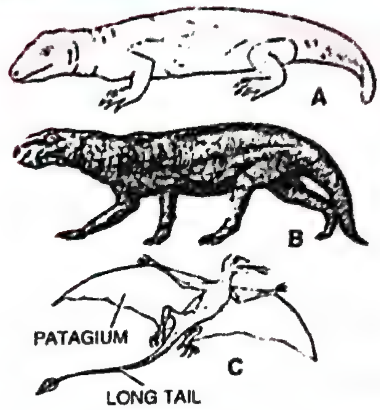


Fig. 4.64. A, Seymouria. B, Lycaenops. C, Rhamphorhynchus.

- *Anguis* (European glass snake-limbless-lizard), *Chameleon pumilus, Vipera russelli*- (the Russell's viper), *Crotalus* (the rattle snake), *Hydrophis* (sea snake),- are all viviparous.
- India's Gahirmath Turtle Research Centre is situated in Orissa.
- Marine turtles lay eggs in pits dug in coastal sand by themselves.
- **Origin of Reptiles** was in Carboniferous period.
- **Origin of Dinosaurs**. Triassic period.
- **Age of Reptiles**. Mesozoic era/Jurassic period.
- **Father of Indian Ophiology** — Dr. Patrick Russell (1727–1805).
- Haffkin's Institute, Mumbai and Central Research Institute, Kasauli (Himachal Pradesh) are well known for the production of anti-venum injections.
- Venom is proteinous and acidic in nature.

Class Aves— The Birds

(L. *Avis*– Bird)

General Characters

1. Birds are bipedal **feathered** and warm blooded (**homoiothermous**) animals, *i.e.*, they are able to maintain a constant body temperature. Their fore-limbs are modified into **wings**. Most of them can fly except flightless birds (*e.g.*, Ortrich). Class Aves has about 9000 species.

2. The hind-limbs are adapted for perching, walking or swimming, etc., and usually bear four, sometimes three and rarely two toes.

3. Except **uropygial gland (preen gland** or oil gland), at the base of the tail, no skin gland is present. Ostrich and parrot lack oil gland.

4. The upper and lower jaws are modified into **beak**, which lacks teeth. Beaks are

adapted to many ways of feeding; seed-crushing, fruit-scooping, flesh-tearing, nector-sipping, wood-chiselling and so on.

5. Legs are modified for walking, hopping, grasping, perching, wading and swimming. Legs bear horny **epidermal scales.**

6. The alimentary canal has additional chambers, the **crop** and **gizzard.** The crop stores and softens the food, however, the gizzard helps in crushing and churning the food. There is a **cloacal aperture.** Gall bladder is absent in some seed-eating birds (graminivorous) such as pigeons.

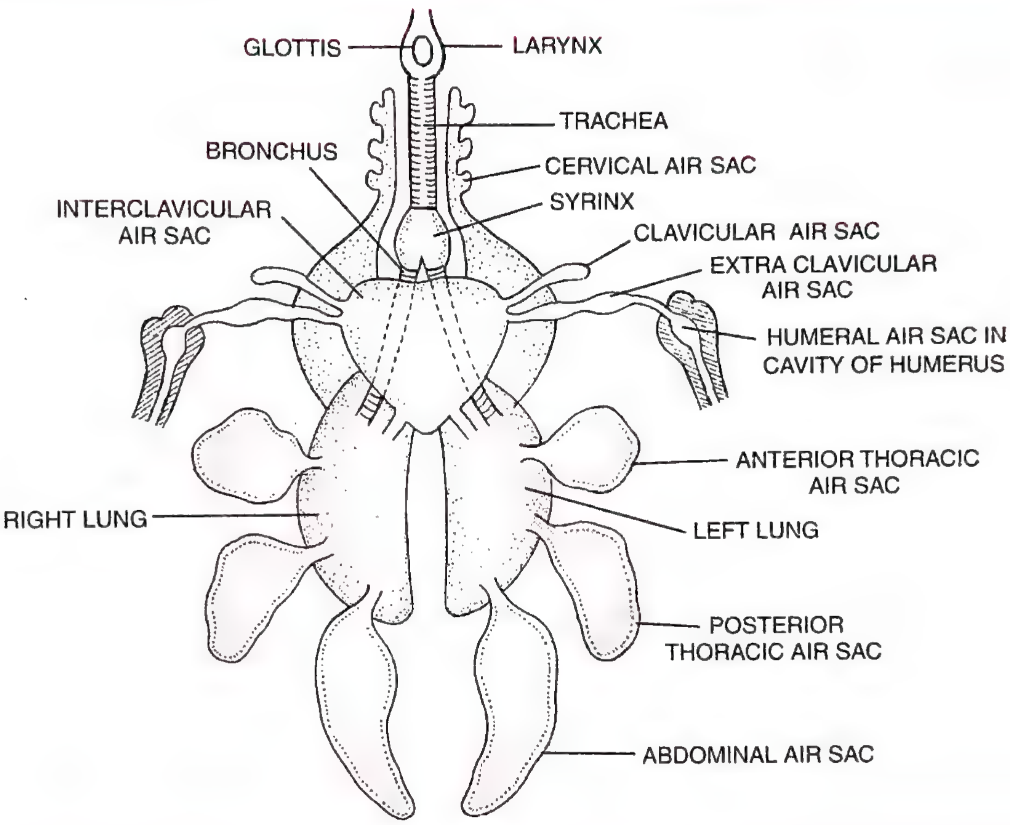


Fig. 4.65. Respiratory System of a bird.

7. Respiration is by lungs. The lungs are spongy and inelastic. **Air sacs** are connected to lungs for supplement respiration. The larynx does not act as a voice box. Voice is produced by a special organ, the **syrinx.**

8. The heart is four-chambered. Sinus venosus is absent. Renal portal system is very much reduced. Red blood corpuscles are nucleated, oval and biconvex.

9. The kidneys are **metanephric** which drain the nitrogenous waste matter (chiefly **uric acid**) into cloaca through the ureters. Urinary bladder is absent except *Rhea americana* (American Rhea— also called "South American Ostrich". This is the only bird that has urinary bladder).

10. Brain is better developed than that of reptiles, of which cerebrum, cerebellum and optic lobes are quite large.

11. Birds have 12 pairs of cranial nerves.

12. Birds have a keen sense of sight but poor sense of smell but Kiwi has good sense of smell. **Pecten** is present in the eyes of birds. Ear openings are present. Each ear consists of three parts: external, middle and internal.

13. Endoskeleton is fully ossified (bony) and the long bones are hollow with **air cavities** **(pneumatic)** to reduce weight. *There is no bone marrow.* The skull is **monocondylic**, i.e., with one occipital condyle. Sternum with a median **keel** for the attachment of flight muscles.

14. Female has usually well developed single left ovary and oviduct. If right ovary and oviduct are present, they are vestigial (nonfunctional).

15. Many birds shows **sexual dimorphism**. All birds are oviparous. Like reptiles birds lay **cleidoic eggs** which are **macrolecithal** and **calcareous**. Four **embryonic membranes** (*e.g.*, chorion, amnion, allantois and yolk sac) are formed.

16. The birds are the most beautiful among the animals. They show **courtship**, nest building, parental care, migration and territorial behaviour.

Aerial or Flight Adaptations in Birds

1. **Spindle-Shaped Body.** It is designed to offer minimum resistance to the wind.
2. **Feathers.** They provide the passage for air and reduce friction to minimum. They also prevent loss of heat and help to maintain a constant temperature.
3. **Wings.** Fore-limbs are modified into wings, which help during flight.
4. **Beak.** Besides procurement of food, the beak is also used for nest-building.
5. **Neck and Head.** Mobile neck and head are very useful for feeding, nest building, offence and defense.
6. **Flight Muscles.** The flight muscles on the breast are greatly developed which help in flight.
7. **Hind Limbs (Legs).** They are well suited for perching.
8. **Endoskeleton.** Most of bones are pneumatic and filled with air instead of bone marrow. It makes the body light. Most of the bones are firmly fused together, which help in flight.
9. **Air Sacs.** These are attached to lungs which serve as reservoirs of air. They may also aid as cooling devices in regulation of the temperature of the body.
10. **Warm-bloodedness.** Birds are warm-blooded animals which is necessary for flight.
11. **Circulatory System.** A large oxygen supply is required for rapid metabolism and warm-bloodedness. It is done by an efficient circulatory system.
12. **Absence of Urinary bladder.** Except *Rhea*, urinary bladder is absent in birds. Excreta is passed out at once. This helps in reducing the weight of the body.
13. **Brain and Eyes.** Brain and eyes are well developed. Equilibrium is maintained by well developed cerebellum of the brain.
14. **Single Ovary.** Presence of a single functional ovary on the left side in the female bird also leads to reduction of weight which is so essential for flight.

Classification

Class Aves is divided into two subclasses:

Subclass I Archaeornithes. Extinct, toothed beak, tail long lizard-like *e.g.*, *Archaeopteryx* (Fig. 4.66).

Subclass II. Neornithes. Modern as well as extinct birds, teeth absent, tail short, *e.g.*, *Struthio*, *Aptenodytes* (Penguin), *Ardea* (Grey heron), *Alcedo* (Kingfisher), *Anas* (duck), *Columba*, Psittacula, *Gallus*, *Tyto*, *Bubo* (Great horned owl), *Phonicopterus* (Flamingo), *Aquila* (Eagle), *Neophron* (Vulture, **Gidh**), *Milvus* (Kite, **Cheel**), *Pavo*, *Corvus* (Crow),

Passer domesticus (House sparrow—**Gauriyya**), Crane (**'Saras'**), Cuckoo (**Papiha**), Eagle (**Baz**), wild goose (**Hans**), hawk (**Basha**), hornbill (**Dhanesh**), Partridge (**Teetar**), quail (**'Bater'**), myna, swift (**Babila**), tailor-bird (**Durzee**), weaver-bird (**Baya**), wood pecker (**Kathphorwa**). Darwin Finches; *Dodo* was pigeon-like bird which became extinct during 17th century in Mauritius.

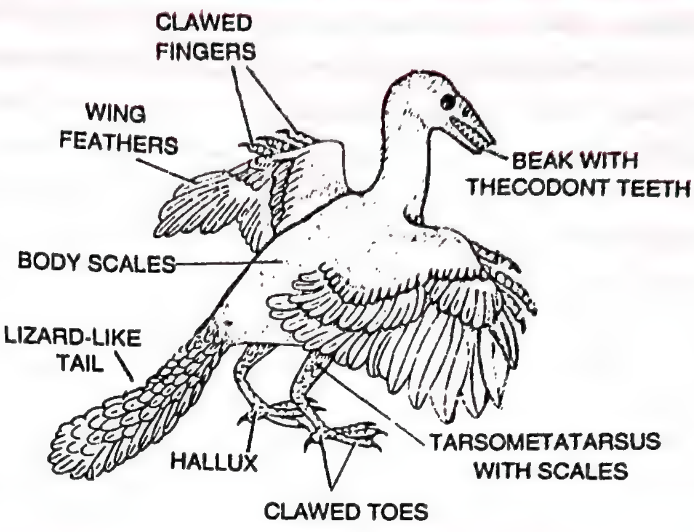


Fig. 4.66. *Archaeopteryx.*

Darwin's Finches. A group of finches (birds) which live only on the Galapagos Islands except for one species which is also found on the Cocos Island. They are named after the naturalist Charles Darwin who visited the islands during his famous voyage on HMS Beagle (Ship) in 1835. Each finch has a different shape of bill to suit its method of feeding. Darwin's observations on these birds were an important influence in helping him to draw up his theory of evolution.

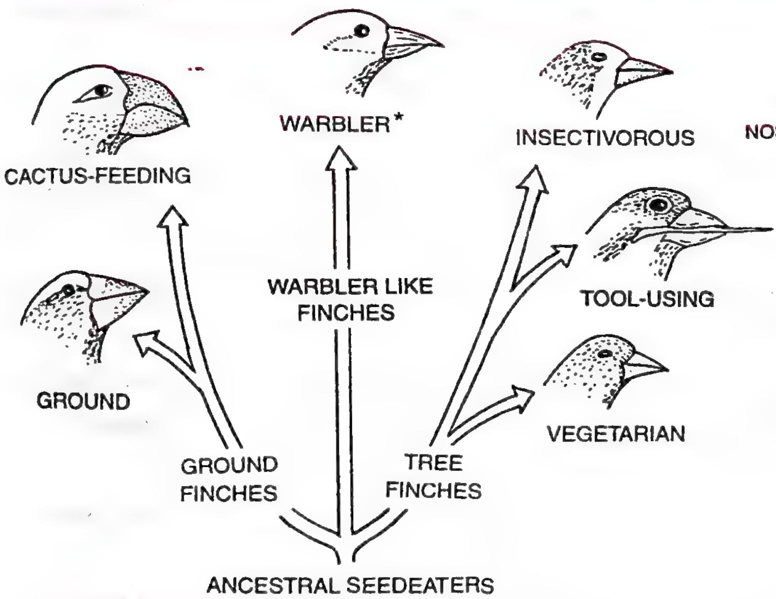


Fig. 4.67. Variety of beaks of finches that Darwin found in Galapagos islands.

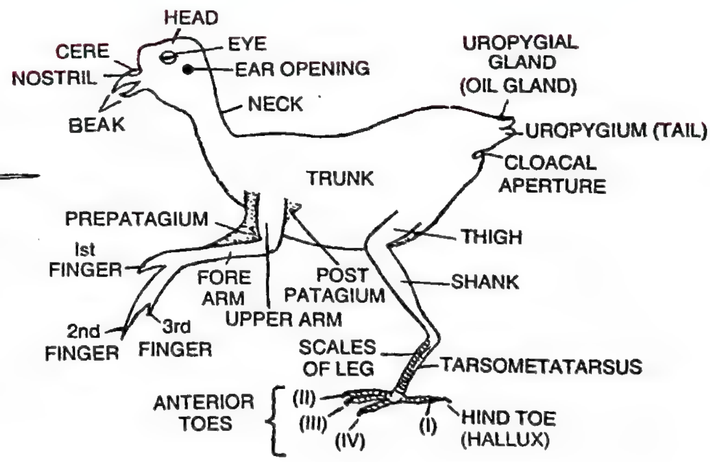


Fig. 4.68. External characters of a typical bird after removing feathers.

External Characters of a Typical Bird (Fig. 4.68)

Birds are bipedal feathered animals. Body is divisible into **head**, **neck** and **trunk**. The head has a beak, patch of fleshy skin, the **cere**, ear holes, nostrils and eyes, Neck may be small or long. The trunk is divisible into **thorax** and **abdomen**. In the thorax fore-limbs are modified into wings. The abdomen bears the hind-limbs which are long and stout bearing usually four or three and rarely two toes. The toes have claws. All birds have scales on their legs. The abdomen possesses a cloacal aperture posteriorly. The ***uropygium*** (*tail*) is usually short. The **uropygial gland** (oil gland) is generally present on the dorsal surface of the tail.

Flightless Birds

Some important flightless birds are **Ostrich, Rhea, Emu, Kiwi, Cassowary, Pen-**

*Warbler – A bird that makes musical sound.

guins and **Island Rail**. **Dodo** was flightless bird of Mauritius which became extinct in 1681. **Moa** is also an extinct flightless bird of New Zealand.

***Ostrich* (*Struthio*).** It is called **Shutarmurg** in Hindi. It is the **largest living flightless bird**. Ostrich has the *largest eyes* of any land animal. Ostrich swallows small stones to aid their digestion of vegetable matter. It can run at the speed of 60 kms. per hour. The male possesses a penis, which serves the copulatory function. Usually one male lives in a group of females. Each foot bears two unequal toes provided with pads, which help the bird in fast running. Ostrich lays the *largest egg* produced by any living bird. It is commonly found in the deserts of Africa and Arabia.

Kiwi (*Apteryx*). It is the New Zealand's Emblem bird. It has a good sense of smell and acute hearing. It finds its prey through its sense of smell. Kiwi has most sensitive beak among birds. It can detect worms in the ground. It has poor eye sight. Kiwi lays the largest egg in proportion to its own size. The male bird builds the nest and incubates sitting on one or more eggs.

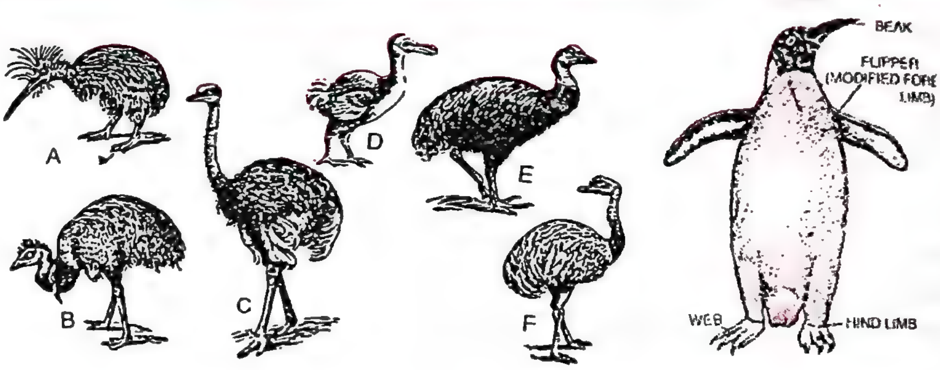


Fig. 4.69. A. Kiwi, B. Emu, C. Ostrich, D. Dodo, E. Cassowary, F. Rhea, G. Penguin.

Aptenodytes (Penguin). Penguins are gregarious flightless birds and live in cold sea waters of the South Pole specially in Antarctica. They feed on fishes, etc. Their wings are modified into swimming **flippers**. Each leg is webbed and has four toes. There is present a thick layer of fat under the skin which prevents the loss of body heat. *Male penguin alone incubates the egg without feeding for two months.*

Rhea (*Rhea*). It is found in South America. Rhea is smaller than Ostrich but its habits are quite similar to Ostrich. It has 3 clawed toes on each foot. Its head and neck are feathered, not naked as in Ostrich. The male is polygamous. It is called "South American Ostrich".

Emu (*Dromaius*). It is the second largest living bird. It is confined to Australia. Emu is invariably monogamous though seen in small parties after breeding.

Cassowary (*Casuarius*). It is the world's third largest flightless bird. It lives in Australia, New Guinea and adjacent islands. It is shy and nocturnal. Each foot has 3-clawed toes. Old males may attack even human beings if disturbed. Cassowary found in the tropical Papua* New Guinea is the world's most dangerous bird.

Flightless birds belong to the super order **Ratitae**.

Flying Birds

The Great Indian Bustard (*Choriotis nigriceps*). It is an inhabitant of the semi-arid areas of Rajasthan, Gujarat and Maharashtra. Hunting for its flesh has reduced its population. It is highly endangered bird. *It is the state bird of Rajasthan.*

***Eudynamis* (Koel, Kokila).** The male sounds like kuoo-kuoo-kuoo. The female is

*Papua and New Guinea were combined to form Papua New Guinea in 1949 and became independent in 1975. This country is in the Pacific ocean to the east of Indonesia.

generally heard during breeding season and has a short and sharp call *kik-kik-kik*, otherwise she is mostly silent. It does not make any nest but lays eggs in the crow's nest. In this way koel is nest parasitic. Male is black. Female is brown and profusely spotted and barred with white. Koel is known as the Indian Nightingale because of its pleasant call.

***Corvus* (Crow).** It is **omnivorous**. The female is usually smaller than the male. Some koels place their eggs in the nests of crow for incubation. Thus, the young ones of the

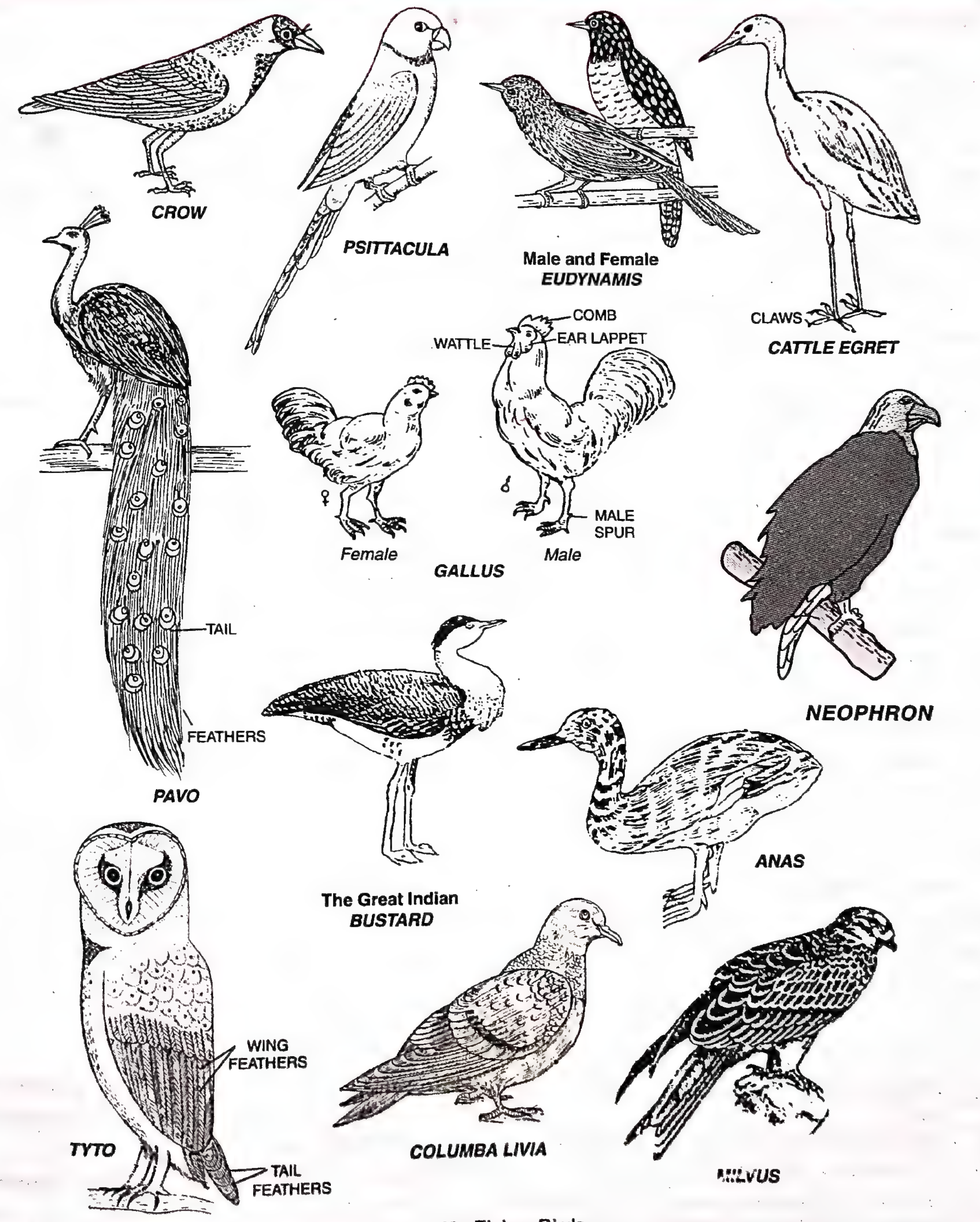


Fig. 4.70. Flying Birds.

koels are also fed by the crow, the foster mother. It eats locusts and other injurious insects but also raids ripening crops like wheat, maize, fruits, etc.

***Psittacula* (Parrot).** The upper beak (mandible) is curved and movable, while the lower beak is fixed. It is an interesting pet, as it immitates human speech. It carries the germs of the disease called *psittacosis*, which can be fatal to persons who come in contact with them.

***Anas* (Duck).** It is well adapted for swimming. It eats mosquito larvae, small fishes, grains and vegetables. Male duck (drake) bears a characteristic copulatory organ. It has great economic importance as it destroys mosquito larvae. Its eggs and flesh are eaten.

***Columba livia* (Pigeon).** Pigeons are gregarious, omnivorous. The cavity of the **gizzard** of the pigeon always contains small pieces of stones and bricks swallowed by the bird. These pieces of stones and bricks help the gizzard in grinding up the food. The pigeons are monogamous. The young ones are fed upon by both male and female on **'pigeon milk'**. The pigeon milk is creamy fluid secreted by the crop of both male and female pigeons, especially during the breeding season. Being a grain eating bird, it harms our crops to some extent. Its faecal pellets is a good manure.

***Gallus gallus* (Red Jungle fowl).** A single cock lives in the company of several hens. They exhibit *sexual dimorphism*. Fowl (common word for cock and hen) provides good food for human beings. Their eggs have good food value and are hence commonly eaten by men.

***Neophron* (Vulture).** It flies very high in the sky for hours together. It acts as a natural scavenger. It makes its nests on the top of the trees. Parental care is offered by either sex. It is called "gidh" in Hindi.

***Tyto* (Barn owl).** It is nocturnal bird. Owls also emit a loud hiss much like that of a large snake such as cobra. Owls have remarkable sharp hearing power and a keen eye sight. Owls are useful to farmers as they feed on rodents (rats, mice, etc.) which destroy the crops. It is called "ullu" in Hindi.

***Milvus* (Kite).** It is a true scavenger. It feeds largely on flesh. Its beak is so made that the bird can tear flesh into pieces. The upper jaw is longer than the lower and is bent down. The kites are destructive to chicks, young turkeys and ducklings. Otherwise they seem to be beneficial to human beings. It is called "Cheel" in Hindi.

***Bubulcus ibis* (Cattleegret, 'Bogla').** It is called the cattle-egret because it is very fond of walking along cattle while they are grazing. Egret makes its nest in colony mostly in the tall trees. The egrets seem to be very beneficial and true friends of farmers as they destroy many insect pests from their fields.

***Pavo cristatus* (Peacock).** It is polygamous. Usually one male lives in the company of four or five females. Before copulation male exhibits sexual display. Male has the bright blue neck, breast and long beautiful tail. Indian peacock is the **National Bird of India**. It is called 'mor' in Hindi.

ADDITIONAL INFORMATION

- T.H. Huxley said "**birds are glorified reptiles**".
- The first fossil of *Archaeopteryx* was found in Germany in 1861.
- The bird **Albatross** can fly throughout the day without flapping its wings even once. It is considered masters of the air.
- **Dove** is the emblem of the sign of peace.
- **Arctic tern** is the champion of all migrating birds. It travels upto 35,200 km in a year. It returns to the same site of previous year.
- The humming bird is the only bird which can fly backward as well as forward.

- Bee Humming bird is the smallest bird in the world.
- Humming birds build the smallest nests.
- Certain humming birds become cold-blooded at night. Certain humming birds also hibernate.
- Colombia has the world's richest diversity of birds.
- The bird Dodo became extinct because of its fearlessness.
- *Guano*— excreta of sea birds.
- **'Wagtail'** migrates from Siberia to India during winter not for breeding, but for feeding.
- **Lagena** is a part of membranous labyrinth of the bird associated with hearing.
- **Ornithology**— study of birds.
- **Nidology**— study of nests of birds
- **Oology**— study of eggs of birds.
- African Fish Eagle is called the Voice of Africa because of its familiar yelping call.
- Bald Eagle is the symbol of the USA.
- **Gentoo Penguin** is the fastest swimming bird.
- Himalayan Bearded Vulture is the largest Indian bird. Previously the Sarus was considered the largest Indian bird.
- Shrews (mammals) have the highest metabolic rate. Humming birds rank along with them in having the highest metabolism of any warm-blooded vertebrate.
- Inaccessible Island Rail (*Atlantisia rogersi*), 12.5 cm, is the smallest flightless bird in the world. Previously little spotted Kiwi 35 cm long was considered smallest flightless bird.
- Ruppell's Vulture (*Gypsa ruepellii*) flies the highest.
- Red Billed Quelea (*Quelea quelea*) of Africa are the most abundant birds. Previously the house sparrow was considered the most abundant species of birds.
- Europe is the only continent where there are no parrots today although their fossils have been found.
- Why does the owl need to rotate its head through an angle of 270°? Because its eyes do not rotate in their sockets. Each eye is fixed like a car headlight.
- Copulatory organ (true penis) is present in ostrich, duck, swan and goose.
- Famous Indian Ornithologist— **Dr. Salim** Ali (Bird man of India).
- **Jatinga** is a village in Assam's North Cachar Hills where birds of various kinds commit mass suicide in large numbers between August and November every year.
- **Baya**, the weaver bird makes the most intricate (complicated) nests.
- The **Swift** is the only bird that uses its own saliva to build nests.
- Swifts are the most aerial of birds. They rarely touch the earth.
- The first and the only poisonous bird on record was discovered recently in Papua, New Guinea by one John Dummbacher. The bird is Hooded pitohui *(Pitohui dichrous)*. The toxin is concentrated in the bird's feathers and skin. It is probably a defence mechanism against hawks and snakes which prey on it.
- Bald Eagle is credited with building the longest nest in the world upto 9.5 feet wide and 20 feet deep.
- Origin of toothed birds- **Jurassic Period.**
- Keoladeo Ghana National Park, Bharatpur, Rajasthan and Chilka Lake Bird Sanctuary, Balagaon, Orissa are famous for birds.
- **Tailor-bird** uses fine fibres to sew two or more leaves with sharp slender beak to make a nest.
- **Himalayan Monal Pheasant** (*Lophophorus impejanus*). The population of the monals has shrunk and is now restricted to certain areas of Himachal Pradesh.
- Any bird with webbed feet is called a **palmidped**.
- The male hornbill bird seals the female while she incubates the eggs by sealing the nest hole.
- All domestic breeds of fowls have descended from the wild species of fowl known as Red Jungle fowl.
- ***Wish-bone*** or **fercula** is formed by the fusion of clavicles and inter-clavicle.
- ***Pygostyle*** is formed by the fusion of caudal vertebrae.
- ***Syrinx*** *is the sound producing organ in birds.* It is absent in ostrich, storks and some vultures.
- **Synsacum** is a composit bone. In fowl, it is formed by the fusion of 16 vertebrae. Last thoracic, 6 lumbar, 2 sacral and 7 caudal vertebrae.
- *Humming bird* is also called "Cuban bee".
- **Types of Feathers. (1) Quill Feathers** — largest and most important in flight. These are futher divided into (i) *Remiges* — feathers of wings. (ii) *Rectrices*— feathers of tail. (iii) *Coverts* — feathers cover-

ing the basis of wing quills and tail quills.

(2) **Contours** — feathers forming the general covering of the body.

(3) **Filoplumes**— delicate, short, hair-like feathers, distributed over the body and among the contour feathers, also called space filling feathers.

(4) **Down feathers** or **Plumules** — short and wooly without shaft (rachis), forming the general covering of the body, providing necessary heat for the incubation of egg by an adult bird, in a young one the down feathers cover body and are called **nestling down feathers** (nestlings are too young birds to leave the nest).

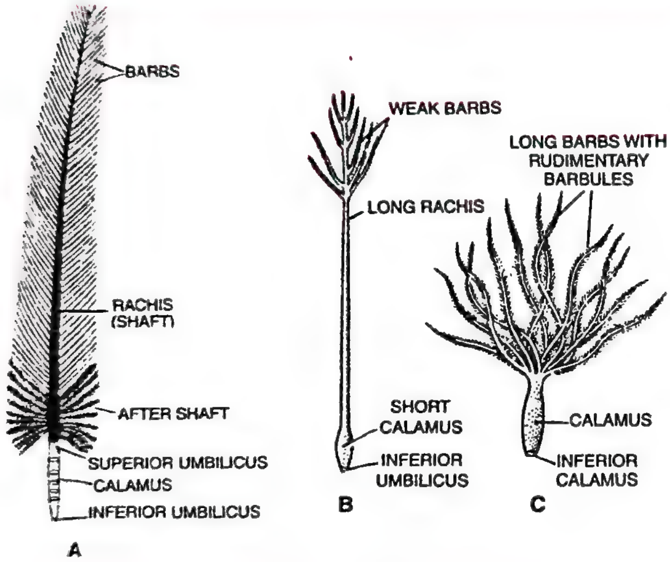


Fig. 4.71. Feathers. A, Quill. B, Filoplume. C, Down.

(5) **Powder down feathers**— help to keep the plumage (assemblage of feathers) clean and in good condition.

(6) **Tactile feathers (vibrissae)** — at the root of beaks or round the eyes.

(7) **Rictal bristles** — modified filoplumes.

- The arrangement or distribution of feathers on the body is called **pterylosis.**
- Haryana has named all its tourist resorts after birds.
- The endangered **Western Tragopan** (Jujurana) is the new state bird of Himachal Pradesh. Monal is the state bird of Uttarakhand and National Bird of Nepal.
- The Western Tragopan locally known as the 'king of the Birds' is included in the Schedule I of the wildlife protection offering fullest legal protection.
- A comb-like structure, the **pecten**, projects from the blind spot into the vitreous humour. The pecten is present in the eye of all the birds except Kiwi (*Apteryx*). Pecten is also found in some reptiles (*e.g., Uromastix*) but it is absent in mammals. The actual function of pecten is not understood but possibly it aids in the nutrition of the eyeball or in accommodation.
- Quills or Flight feathers were once used as pens. The quills were usually taken from the bird geese.
- The veterinary use of **diclofenac**, an anti-inflammatry drug, is the main reason for the decline in the vulture population in India.
- Both scales and feathers are epidermal in origin.
- **Ornithologist.** Person studying the birds.
- **Largest Bird Egg.** Ostrich, 175 mm in diameter.
- **Smallest Bird Egg.** *Mellisuga minima* (Humming bird).
- **Largest bird** – Ostrich, height 2.5 metres, weight 150 kg.
- **Largest Wing–Span–*Albatross*.** Wingspan is more than 3 metres.
- **Longest Tail.** A rare Japanese bird named *Onagadoris* has the longest tail which is eleven metres long.
- **Smallest Bird.** Bee Humming bird of Cuba (less than 6 centimetres, weight 4 gms).
- **Fastest Flying Bird**– Swift, Flying speed is 171 kilometres per hour.
- **Seagull** can drink salt water because it has special glands that filter out the salt.
- **Fastest Running Bird on Land.** Ostrich.
- **Baaz** (Eastern Goshawk) state Bird of Punjab.
- **20th March** — World Sparrow Day.

Class Mammalia— the Mammals

(L. *Mamma*– Breast)

General Characters

1. These animals are warm blooded, hairy and have mammary or milk producing glands. **(mammary glands).** They are the only animals which nourish their young ones with milk. There are about 4,000 species of mammals found in the world.

2. They are homoiothermous (warm blooded).

3. Oil glands (**sebaceous glands**) and sweat glands (**sudoriferous glands**) are present in the skin.

4. Teeth are of different types (**heterodont**) and are embedded in the sockets of jaws (**thecodont**). These are developed twice during the life-time of the animal (**diphyodont**), milk and permanent teeth.

5. Except a few, mammals possess **seven cervical** (neck) **vertebrae.**

6. The skull is **dicondylic** *i.e.*, with two occipital condyles.

7. Respiration is by lungs.

8. They possess a muscular **diaphragm** dividing trunk into thorax and abdomen.

9. The coelom is divided into four cavities; a **pericardial cavity** lodging the heart, two **pleural cavities** each containing the lung and an **abdominal cavity** having the rest of viscera.

10. The heart is four chambered. Sinus venosus is absent. The red blood corpuscles are without nucleus. Renal portal system is absent.

11. The brain has large cerebrum and cerebellum. Optic lobes are divided into four lobes called **corpora quadrigemina. Corpus callosum** connects the two cerebral hemispheres internally.

12. 12 pairs of cranial nerves are present.

13. Each ear consists of three parts: external, middle and internal. **Pinna** is a part of **external ear. Middle ear** has 3 bony **ear ossicles** (*malleus*— hammer shaped, *incus*-anvil shaped and *stapes*-stirrup shaped). **Internal ear** has **organ of *Corti,** the actual hearing organ.

14. Except egg laying mammals, they are viviparous. There are present four embryonic membranes: chorion, amnion, allantois and yolk sac. Except egg laying mammals a well developed **placenta** is present.

15. Mammals occur in all sorts of habitats. They are dominant animals and are capable to learn because of their better developed brain.

Examples. Oviparous– *Ornithorhynchus* (Duck Billed Platypus), *Tachyglossus = Echidna* (Spiny Anteater).

Viviparous — *Macropus* (Kangaroo), *Pteropus* (Large bat), *Camelus* (Camel), *Macaca* (Monkey), *Rattus* (Rat), *Canis* (Dog), *Elephas* (Elephant), *Felis* (Cat), *Delphinus* (Common dolphin), *Equus* (Horse), *Balaenoptera* (Blue whale), *Panthera tigris* (Tiger), *Panthera leo* (Lion).

Classification

Living mammals are divided into two sub-classes.

1. **Sub-class Prototheria.** Prototherians are considered to be the most primitive mammals which are only restricted in Australia and its neighbouring islands (Tasmania, New Guinea). Besides egg-laying habit, they have several reptilian characters including a cloaca. They lay eggs containing ample amount of yolk. Subclass prototheria includes one **order Monotremata** *e.g., Ornithorhynchus, Tachyglossus– (Echidna).*

2. **Sub-class Theria.** They produce young ones. Subclass Theria is divided into two infraclasses; Metatheria and Eutheria.

*Name of scientist.

I. **Infra-Class Metatheria.** Now they are found mainly in Australia, New Guinea and S. America. Females have a **marsupium** or brood-pouch for rearing young ones. Infra-class metatheria includes one **Order Marsupialia**. Mammals of this order are called **marsupials** or pouched mammals, *e.g.*, *Macropus*, *Didelphis* (Opossum) and *Phascolarctos* (Koala).

II. **Infra-class Eutheria.** They are provided with true placenta, hence called **placental mammals**. The embryos are retained in the uterus (womb) till an advanced stage.

Differences between three groups of Mammals

Prototheria	*Metatheria*	*Eutheria*
1. Oviparous	Viviparous	Viviparous
2. No pinna	Pinna present	Pinna usually present
3. No nipples (mammae)	Nipples abdominal	Nipples abdominal or thoracic
4. No marsupial pouch	Marsupial pouch often present.	No marsupial pouch
5. Digestive and urinogenital tracts open into a cloaca. Cloaca opens outside through cloacal aperture.	Anus and urinogenital aperture open into a shallow cloaca surrounded by a common sphincter	Digestive and urinogenital tracts open out by separate apertures.
6. Corpus callosum is small or absent.	Corpus callosum is small or absent.	Corpus callosum is large and well developed. It connects two cerebral hemispheres of the brain internally.
7. No scrotum.	Scrotum in front of penis.	Scrotum behind penis.
8. No placenta.	Placenta is less developed.	Placenta is well developed.

Orders of Eutheria

Some of the principal orders of placental mammals are briefly described here.

(1) **Insectivora** (L. *insectum*– insect, *vorare*– to eat). Testes are abdominal. The water shrew is the tiniest mammal which is as large as a human thumb *e.g.*, shrews, moles and hedgehogs. (2) **Dermoptera** (Gk. *derm*– skin, *pteron*– wing). A hairy skin fold called **patagium** extends like a parachute from neck to tail for gliding, *e.g.*, flying lemours. Actually, flying lemurs are neither true lemurs nor do they fly. (3) **Chiroptera** (Gk. *Cheiros*– hand, *pteron*– wing). They are flying mammals. The forelimbs are modified into **wings,** *e.g.*, bats and flying foxes. The **vampire bats** feed on the blood of mammals including man. (4) **Edentata** (L. *edentatus*– toothless). They are toothless. This order includes the armadillos and sloths of South America. (5) **Pholidota** (Gk. *pholis*– a horny scale). The body of these mammals is covered with overlapping horny scales with sparse hair in between. Teeth are absent, *e.g.*, *Manis* (scaly ant eater or pangolin). (6) **Primates** (L. *primus*– of the first rank). Primates have highly developed brain. The living primates include **prosimians** (meaning before monkeys) and **simians**. The prosimians include lemurs, lorises and tarsiers. The simians include monkeys, apes and men. (7) **Rodentia** (L. *rodo*– gnaw). They have one pair of sharp chisel-like incisors in each jaw. The canines are absent, leaving a toothless space, the **diastema** in the jaw, *e.g.*, rats, mice, squirrels, guinea-pigs and porcupines. (8) **Lagomorpha** (Gk. *logos*– hare, *morphe*– form). They have two pairs of incisors in the upper jaw and one pair of incisors in the lower jaw and no canines, *e.g.*, rabbits and hares. (9) **Cetacea** (L. *cetus*– whale). They have fish-like body, well adapted for aquatic life. They have fin-like fore limbs, but *no hind limbs*. Testes are abdominal. The skin has a thick layer

of fat called **blubber** serving as reserve food, an insulator for reducing the specific gravity. Pinnae are reduced or absent. *Hair are only on lips. They do not have sweat and oil glands, e.g.,* whales, dolphins and porpoises. *Blue whale is the largest living animal.* Whales normally lack pelvic girdle and hind limbs. The Green land whales, however, possess vestiges of pelvic girdles and bones of hind limbs inside the body (10) **Carnivora** (L. *Caro*– flesh, *vorare*– to eat). They are flesh eating mammals. These animals have sharp pointed canines, strong jaws and well developed claws, *e.g.*, dog, cat, wolf, jackal, fox, cheetah, lion, tiger, hyaena, mongoose, bear, panda, otter, seal, walrus, sea lion. *Cheetah is the fastest runner.* It can cover a distance of 120 Km in one hour. (11) **Proboscidea** (Gk. *pro*– in front, *boskein*– to eat). They have a long muscular trunk. They are thick skinned animals hence called **pachyderms** (Gk. *pachys* – thick, *derm* – Skin). They are the *largest land animals, e.g.,* elephants. (12) **Sirenia** (Gk. *siren*– sea nymph). They are herbivorous aquatic mammals with fin-like forelimbs and no hind limbs. *They have few hairs and do not have external ears.* They have thick **blubber**. Testes are abdominal. The males have tusks, *e.g.*, Manatee, Seacows. (13) **Perissodactyla** (Gk. *perissos*– odd, *dactylos*– toes). They are herbivorous **odd-toed hoofed mammals** or **ungulates** (L. *ungula*– hoof) or hoofed which have an odd number of toes (1 or 3). True horns with a bony core are never present. The stomach is of non-ruminating type (these are not cud chewing animals) *e.g.*, horses, asses, mules, zebras, tapirs and rhinoceros. (14) **Artiodactyla** (Gk. *artios*– even, *dactylos*– digit). They are herbivorous **even toed hoofed mammals** or ungulates (hoofed) which have even number of toes (2 or 4). True horns or antlers are present in many animals of this order. Many even toed hoofed mammals like cow and camel are ruminants or cud-chewing. The four chambered stomach of cow (Fig. 4.80) is capable of digesting cellulose of plant materials by micro-organisms present in the rumen (first part of their stomach) *e.g.,* cows, buffaloes, sheep, goats, deer, antelopes, yaks, camels, giraffes, pigs and hippopotamuses.

***Ornithorhynchus* (Duck-billed Platypus).** It lays eggs in the nests. The beak or bill is broad and flat just like a duck, hence named as duck-billed platypus. *Pinnae are absent.* Both the webbed feet and flattened tail help in swimming. *Mammary glands are present, but nipples or teats are absent. Male can be distinguished from the female as the male has a poisonous* **spur** *on each hindlimb. These spurs mark sexual dimorphism.* Platypus has some characters common with the reptiles; egg laying habit, reptilian type of excretory system, some endoskeletal features, etc. It is a "connecting link" between reptiles and mammals. It is found in Australia, including Tasmania*.

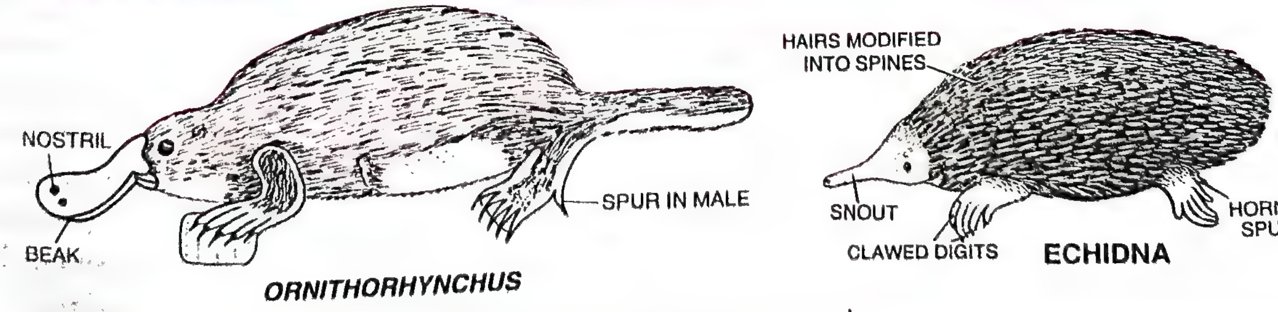


Fig. 4.72. Egg- laying mammals.

***Echidna* or *Tachyglossus* (Spiny Anteater).** The body is covered with strong pointed spines (modified hairs). Teeth are absent in adult. Ear pinnae and tail are absent. Feet are

*Tasmania is an island of Australia.

without webs. Male Echidna also has a hollow **tarsal (horny) spur** on each hind leg connected to a poison gland in the thigh. The teats are absent. Female Echidna lays only one egg. Male Echidna also has mammary glands secreting milk to feed the young. This condition is known as **gynaecomastism.** Spiny anteater can roll itself into a ball to surprise the attacker. It is found throughout Australia and Tasmania.

Macropus **(Kangaroo).** Female Kangaroo has a **marsupial pouch** in which the immature young ones are fed by the mother. Long thick stout tail makes a tripod with hind limbs. The leather of the kangaroo is water proof. Its flesh is eaten. It is a native of Australia, Tasamania and neighbouring islands.

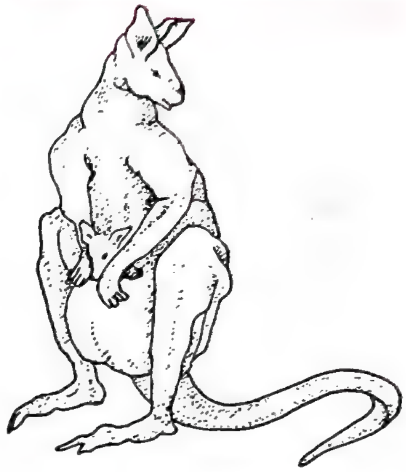


Fig. 4.73. *Macropus.*

Sorex **(Shrew).** Its saliva contains a poisonous substance which helps the animal to capture the prey. They are untameable and hence their name. The water shrew is the *smallest mammal* as large as a human thumb.

Hemiechinus **(Hedgehog).** When disturbed it rolls itself into a ball. The skin is covered with short spines intermingled with hair except on the belly. The spines are modified hair which protect the body. The hedgehog is useful as it destroys insects.

Dasypus **(Armadillo).** *Dasypus novemeinctus*, the nine-banded armadillo is found in N. America. Some species of armadillo are also present in S. America. These are the only living mammals that have **bony plates in their skin**. The plates are intercepted by hair. At the time of danger, it rolls up into a ball for protection. It is nocturnal, scavenger and lives in burrows. It shows **polyembryony** in which one zygote produces four to eight young ones of the same sex. *Mycobacterium leprae* (bacteria which cause leprosy) can grow in Armadillo.

Bats. *The bats are the only mammals which have wings and can really fly*. The eyes are usually not functional. The bats use a highly developed echo-apparatus, a radar system of their own. Supersonic sounds emitted by them vibrate through the air and then strike upon any object in their way and are deflected back and instantly "picked up" by their ears. These *warning* echoes enable bats to locate and evade obstacles in their course. The baby bat clings tightly to its mother's body and its mouth holds one of her teats in a permanent grip. The bats are classified into two main groups.

Differences between Large Bats (Flying Fox) and Small Bats

Large Bats (Flying Fox)	*Small Bats*
1. Frugivorous (fruit eating).	1. Insectivorous (insect-eating) except a few that suck blood, called vampire bats.
2. Head fox-like, snout elongated.	2. Snout short and stout.
3. Pinna is small, simple and without earlets.	3. Pinna is usually large bearing earlets (small lobes).
4. First and second fingers clawed.	4. Only first finger (thumb) clawed.
5. Tail is absent.	5. Tail is present.
6. Interfemoral membrane (membrane joining the legs with the tail) is very narrow and does not include the tail. Example : *Pteropus*.	6. Interfemoral membrane is very large and includes the tail. Example : *Scotophilus*.

(a) **Frugivorous bats.** They are large sized and fruit eating bats. Some bats bring about cross pollination as in *Kigelia pinnata* (Sausage tree— an Angiosperm). These bats are also harmful as they damage the fruits by chewing their juice only, *e.g., Pteropus* (Large bat or Flying Fox).

(b) **Carnivorous bats.** They are small sized insect eating bats but rarely they are also bigger in size. These bats are useful as they destroy insects, *e.g., Scotophilus* (Small bat).

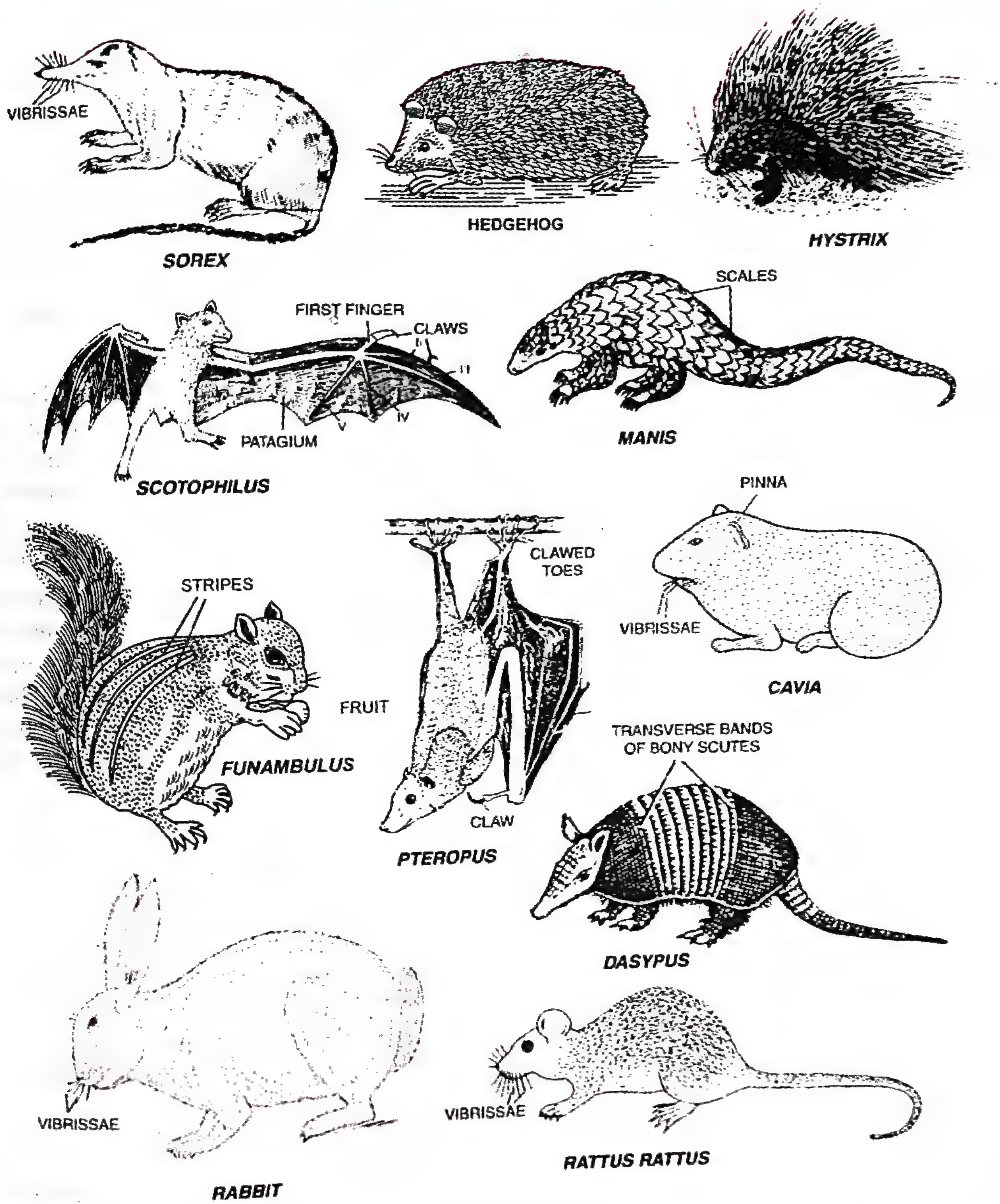


Fig. 4.74. Some Eutherians.

***Manis* (Scaly anteater or Pangolin).** In India, it can be seen in the hilly tracts of Assam, Sikkim and South India. The body is covered with **epidermal scales** except on snout and under surface. It is a nocturnal. It breaks open the termite and ant nests with its strong claws and inserts its long sticky and highly protrusible tongue. It withdraws its tongue to swallow the insects stuck to it into the mouth. **It does not have teeth**. In defence, it rolls up its body into a ball. The pyloric stomach of this mammal has small pebbles or stones and works like the gizzard of some birds, hence the name bajra kit (*i.e., stone eater*).

Rattus rattus (The common house rat). It is **herbivorous**, **fossorial** and **nocturnal** animal, and undergoes **hibernation**. It shows a sort of **sexual dimorphism**. It is a prolific breeder. Its **gestation** period is about 22 to 23 days. The rat breeds more than four times in a year producing 6-8 young ones in each litter. Average age of a rat is 3 years. Both fore and hind limbs are *pentadactyle*. Each limb is made up of proximal segment, the **stylopodium**, middle segment, the **zeugopodium** and distal segment, the **autopodium**. Typical walking pads are present on the palms and soles. The palms and soles lack hair.

***Cavia* (Guinea pig).** Due to the absence of canines, a toothless space, the **diastema** is present between the incisors and pre-molars. It has no tail. It is a prolific breeder. It is an excellent laboratory animal used in various laboratory experiments.

***Funambulus* (Striped squirrel).** It builds nests. It feeds on seeds, nuts and fruits (**frugivorous**). The body is with three or five longitudinal stripes of dark colour on the back. They are world wide in distribution except Australia and its neighbouring islands.

***Hystrix* (Porcupine).** Indian porcupine (*Hystrix indica*) favours rocky and hilly areas. It is nocturnal. It can be very destructive for gardens and crops. The body bears long, rigid, erectile spines which are infact modified hair. The spines are excellent weapons of offence.

Rabbit (*Oryctolagus cuniculus*). Rabbit is a **herbivorous, coprophagous, crepuscular, cursorial, fossorial,** and **polygamous** animal. It is a prolific breeder. The upper lip is longitudinally grooved and, therefore, the incisor teeth are visible. Such a divided lip is called **hare lip**. The fur of the rabbit is used for making gloves, caps, purses, etc. By digging their burrows they destroy the golf lawns and sports grounds.

Differences between Rabbit and Hare

Rabbit (Oryctolagus)	*Hare (Lepus)*
1. Rabbit is fossorial.	1. Hare makes small excavations under bushes or in grasses for shelter.
2. It is gregarious.	2. It leads mostly a solitary life.
3. It is crepuscular.	3. It is nocturnal.
4. It can be domesticated.	4. It lives in wild stage.
5. It gives birth to 6-8 young ones in a litter.	5. It gives birth to 2 young ones in a litter.
6. Young ones of rabbit are blind, hairless and deaf at the time of their birth.	6. Young ones of hare are neither naked nor blind and deaf at the time of their birth.
7. Hind limbs and pinnae are comparatively small.	7. Hind limbs and pinnae are comparatively large.
8. Fore and hind limbs are strongly clawed for burrowing.	8. Both the limbs are not strongly clawed.

***Balaenoptera musculus* (Blue whale).** Whales are the *largest animals* in existence. They are the inhabitants of the open ocean. They are gregarious and carnivorous. It swims with the help of powerful tail and **flippers** (fore limbs). *The skin lacks hair, except a few hair present on the lips. The skin does not have sweat and oil glands. Pinnae are not found in whale.* Oil extracted from its blubber has great economic importance. Longest animal with one nostril (naris) is whale. Whales are hunted mainly for their oil.

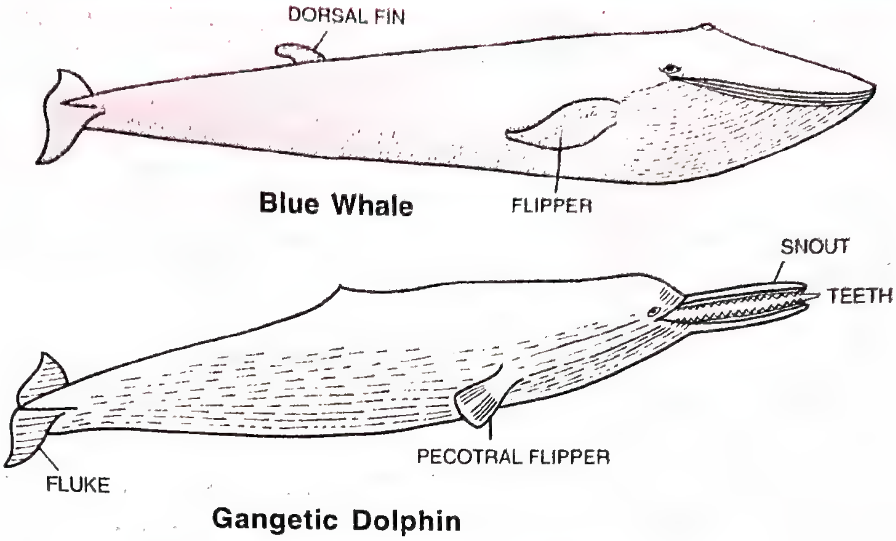


Fig. 4.75. Two cetaceans.

***Platanista gangetica* (Gangetic Dolphin).** They are found in Ganges, Brahmputra, Indus and their larger tributaries. They do not enter the seas. Paired pectoral flippers (fins) are more or less triangular in shape. The dorsal fin is rudimentary and is seen as fleshy ridge. The sweat and oil glands have little value for aquatic mammals, therefore, they are absent.

Delphinus is common dolphin.

***Panthera leo* (Lion).** Lions are found in Africa and India. *In India they are now confined to the Gir Forest in Gujrat state.* They exhibit sexual dimorphism. Only males bear longer hairs (mane) around the neck. About 3 years old female is capable of giving rise to her first litter. The period of gestation is about 116 days. Male lion looks after the young ones and often gets food for them. The life span of a lion is from 20–30 years.

***Panthera tigris* (Tiger).** Tigers are found in India, China and Indonesia. They prefer the places with humid evergreen forests. Tigers are good swimmers. They are striped and with short hair. As in other carnivores the limbs are digitigrade. Canine teeth are well formed and very useful in feeding. Tigers may live about 18 to 19 years. The first **white tiger** was captured in the forest of Rewa in Madhya Pradesh in 1951. It was bred with an ordinary tigress. Now all white tigers are progeny of this white tiger. White tigers are similar to ordinary tigers except they lack melanin pigment. *Tiger is national animal of India.*

***Herpestes edwardsi* (Common Mongoose).** It is carnivorous. The fight between a mongoose and a snake is very common. A common mongoose produces five litters in a year and each litter has two to three young ones.

***Odobenus* (Walrus).** It is a marine carnivorous found in Arctic ocean. The upper canines are very long, downwardly directed, forming tusks in both the sexes. The tusks are used for digging up food. Fore limbs are modified into paddle like structures which are primary swimming organs. The penis is very large. Walrus comes to land for breeding and it is thought that it breeds once in three years.

***Phoca* (Seal).** It is a marine carnivore which visits land for rest and breeding. The seal is usually gregarious. The limbs are paddle-like with webbed digits adopted for swimming. They are hunted for oil yielding blubber and skins. Seal lacks pinnae.

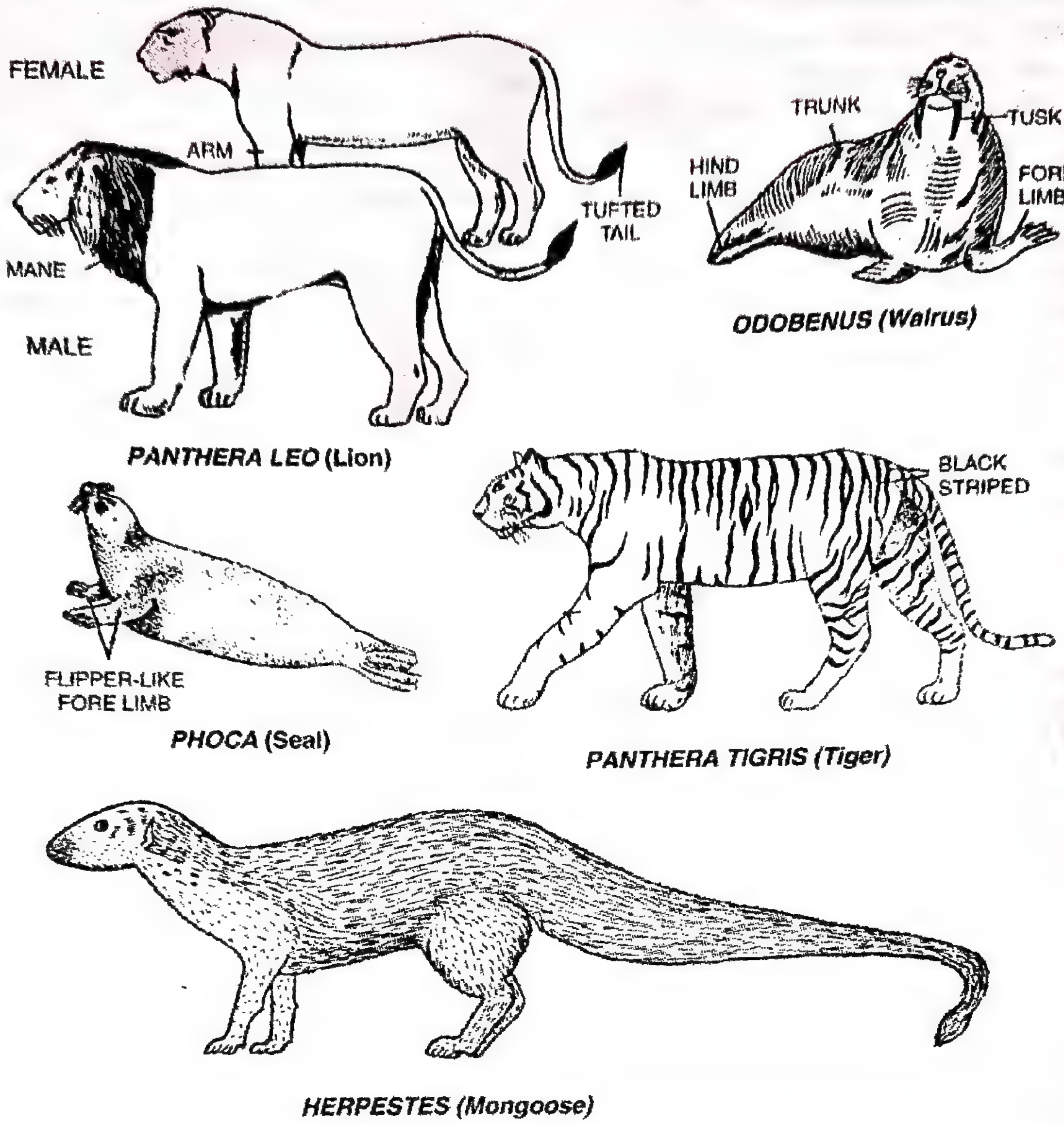


Fig. 4.76. Some Carnivorous mammals.

Elephants. *The largest living land animals.* The nose and upper lip are modified as an elongated **proboscis** (trunk or snout). Two upper **incisors** are modified as **tusks**. *An African elephant has the largest ears in the animal kingdom.* Females have smaller tusks than males. Canines are absent. Elephants have most acute sense of smell among mammals. Elephants use their tusks for defence. Elephants are the only animals with four knees. They are the only animals that cannot jump. Elephants are **pachyderms** (*i.e.*, thick skined). There are two species of elephants in existence; *Elephas indicus*, the Indian elephant, and *Elephas* (= *Loxodonta*) *africana*, the African elephant.

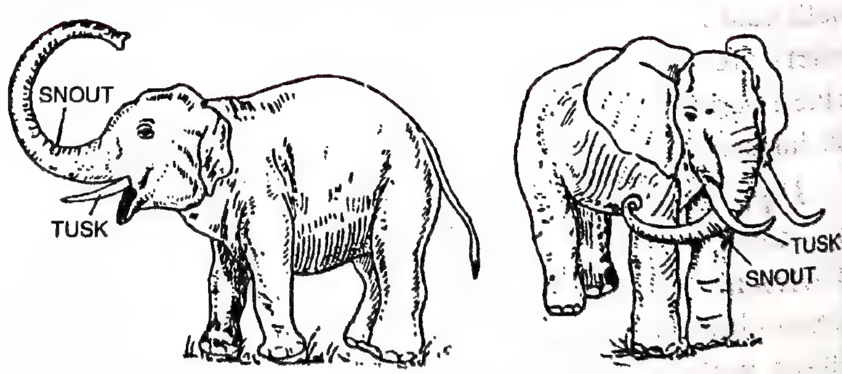


Fig. 4.77. A, Indian elephant; B, African elephant.

Differences between Indian and African Elephants

Indian Elephant (Elephas indicus)	*African Elephant (Elephas africana)*
1. Found in Southern Asia (India, Burma, Thailand, Srilanka, etc.).	1. Found in Africa.
2. Body about 3 m high.	2. Body about 3.45 m high.
3. Pinnae small and triangular.	3. Pinnae large and rounded.
4. Forehead is high domed with a cleft.	4. Forehead is low, flat without a cleft.
5. Tusks are smaller.	5. Tusks are longer.
6. Rounded back.	6. Concave back.
7. It can be domesticated and trained to do work.	7. It can not be easily domesticated or trained.

***Equus zebra* (African Zebra).** The horns are absent. No two zebras are striped alike. Zebra stripes are as individual as human thumb prints. The organs of smell are well developed. Sense of hearing is exceptionally very strong and acute.

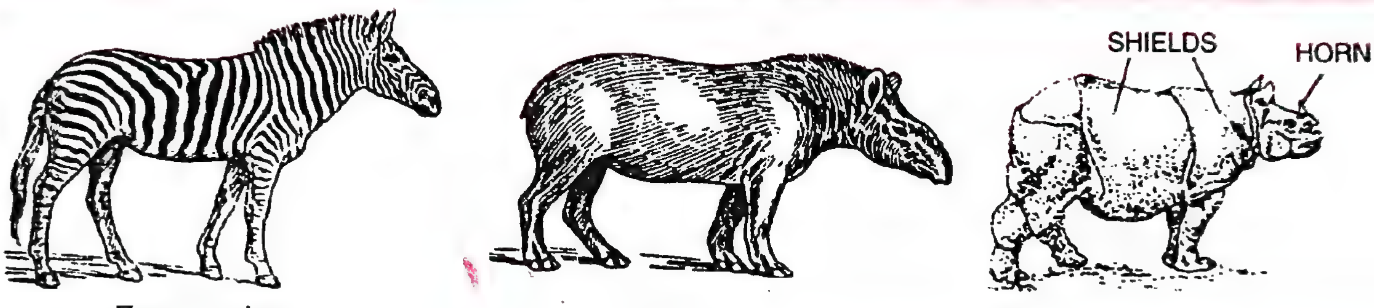


Fig. 4.78. Odd-toed hoofed mammals.

***Tapirus* (Tapir).** It is found in Central and South America and South East Asia. It is the most primitive of modern perissodactyles. It is nocturnal and herbivore which is fond of forests and water. Tapir has a short proboscis (snout) formed of the nose and upper lip.

***Rhinoceros unicornis* (Indian one horned rhinoceros).** In India it is restricted to Assam state. It is also found in Nepal. The thick skin is almost hairless and is divided into big shields by heavy folds. Rhinos with two horns over their snout are found in Africa and south east Asia. The horns grow throughout life and, if lost, are replaced. Many legends and beliefs are attached to this animal. Its horn is believed to have some medicinal value. The urine is considered antiseptic. The great one horned rhino is next to elephant in size among the largest land mammals. **This is the second largest land animal.**

Hippopotamus. 'Hippopotamus' is a Greek combination of 'hippo and potamus' meaning 'horse of the river' hence means **'river horse'**. It is only found in the rivers and lakes of **Africa**. During day it remains in water but it comes out on land at night to feed on the surrounding vegetation. Thus it leads an amphibious life. The skin is thick, smooth and almost without hair. Each limb has four digits which are partially webbed. It can remain submerged in water for five minutes. It gives birth its young one under water. The sweat of Hippopotamus is red in colour.

***Camelus* (Camel).** Only two species of camel exist.

(i) *Camelus dromedarius* (Arabian Camel). It is a single humped camel extensively found in South Western Asia and North America. It is domesticated in North-Western India.

(ii) *Camelus bactrianus*. (Bactrian Camel). It is the two humped camel found in Gobi desert in Central Asia, the United States and also Ladakh, (part of J & K, India).

The hump contains reserve food in the form of fat, which provides water as well as heat, when metabolized. The stomach is three chambered (**rumen, reticulum, abomasum**) and its wall forms a number of sacculated structures usually called **water pockets.** *Omasum, fourth part of stomach of cow, is absent in camel.* Water pockets do not store water. Red blood corpuscles of camels are oval. The RBCs are denucleated as in other mammals.

Giraffa **(Giraffe).** They are now restricted to tropical Africa. It is the *tallest living animal* measuring up to 16 feet high. Head of both the sexes has small unbranched horns that are never shed. Upper canines are absent. Tongue is long and sensitive and used in browsing on trees. Vocal cords are absent. Thus the giraffe has no voice and can deliver a message to another giraffe only by moving its tail. Neck is long bearing seven cervical vertebrae.

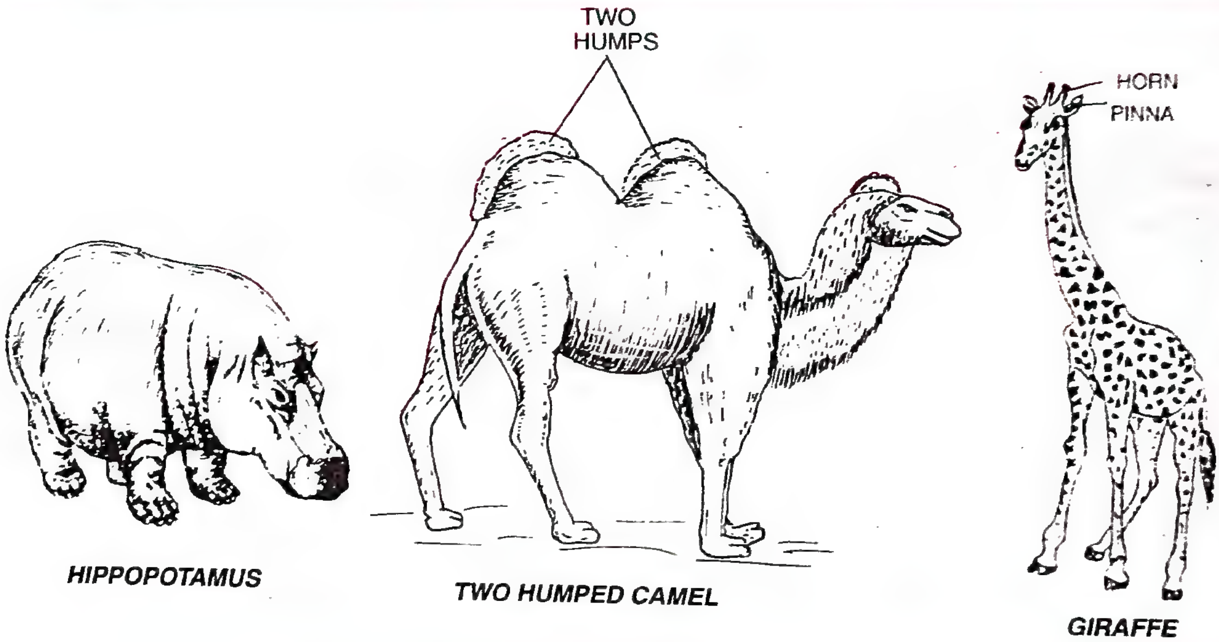


Fig. 4.79. Even-toed hoofed mammals.

Bos indicus (cow). It is found in India and Africa. It is also called 'humped cattle'. It is characterised by presence of prominent hump, upright horns a long face and dropping ears. The stomach of cow (Fig. 4.80) is four chambered **rumen** (paunch), the **reticulum** (honey comb), **Omasum** (psalterium) and **abomasum** (rennet). Ruminant animals like cow chew the cud.

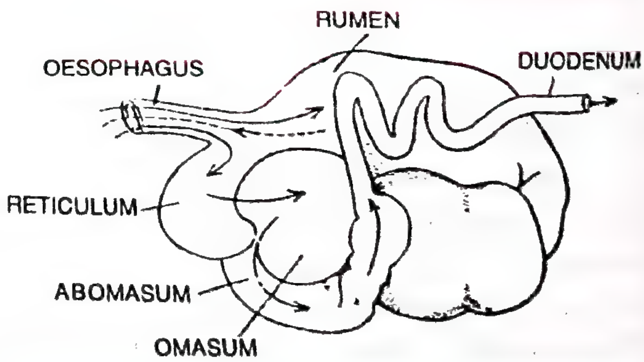


Fig. 4.80. Ruminant stomach of cow.

Primates. They include prosimians and simians.

Prosimians. The lemurs, lorises and tarsiers are called **prosimians.** (i) *Lemur.* It is mostly found in Madagascar and neighbouring islands. It has long and non-prehensile tail. It has poor vision. (ii) *Loris.* Loris is also found in India. It has larger forwardly directed eyes. It does not have tail. **Slender loris** is found

in the forests of South India (Kerala, Tamil Nadu, Karnataka and Andhra Pradesh). **Slow loris** is found in the tropical forests of north-eastern India including Assam. (iii) *Tarsier*. It lives in Philippines and adjacent islands. It has very large eyes and a tuft of hair at the end of the tail. The tarsal region of foot is long hence its name is tarsier.

Simians. The monkeys, apes and men are called simians.

Monkeys. The monkeys are of two kinds : new world monkeys and old world monkeys.

Differences between New World Monkeys and Old World Monkeys

New World Monkeys (South American Monkeys)	*Old World Monkeys (African and Asian Monkeys)*
1. Found in central and South America.	1. Found in Asia including India and Africa.
2. Cheek pouches absent.	2. Cheek pouches present.
3. Nose flat. The nostrils are set wide apart.	3. Nose raised. The nostrils are closer together.
4. Ischial callosities are absent.	4. Thick coloured pads, the ishcial callosities, on buttocks to sit upon, present.
5. Tail is prehensile and is used to hang from trees. *Example* : Spider monkey.	5. Tail is not prehensile and is not used to hang from trees. *Examples* : Rhesus monkey, Langur.

Apes. From the evolution point of view, they are the nearest mammals which resemble men in many aspects. Men and apes had common ancestors. They have longer forelimbs than the hind limbs. They do not have tail. Face expression like pleasure, surprise, laughter and anger can be seen. They are chiefly arboreal, diurnal, omnivorous and gregarious. They have very prominent brow ridges. Apes are capable of communication by vocal means. Examples of apes are : (i) **Gibbon** (*Hylobates*). It is the smallest, cleanest and most gentle

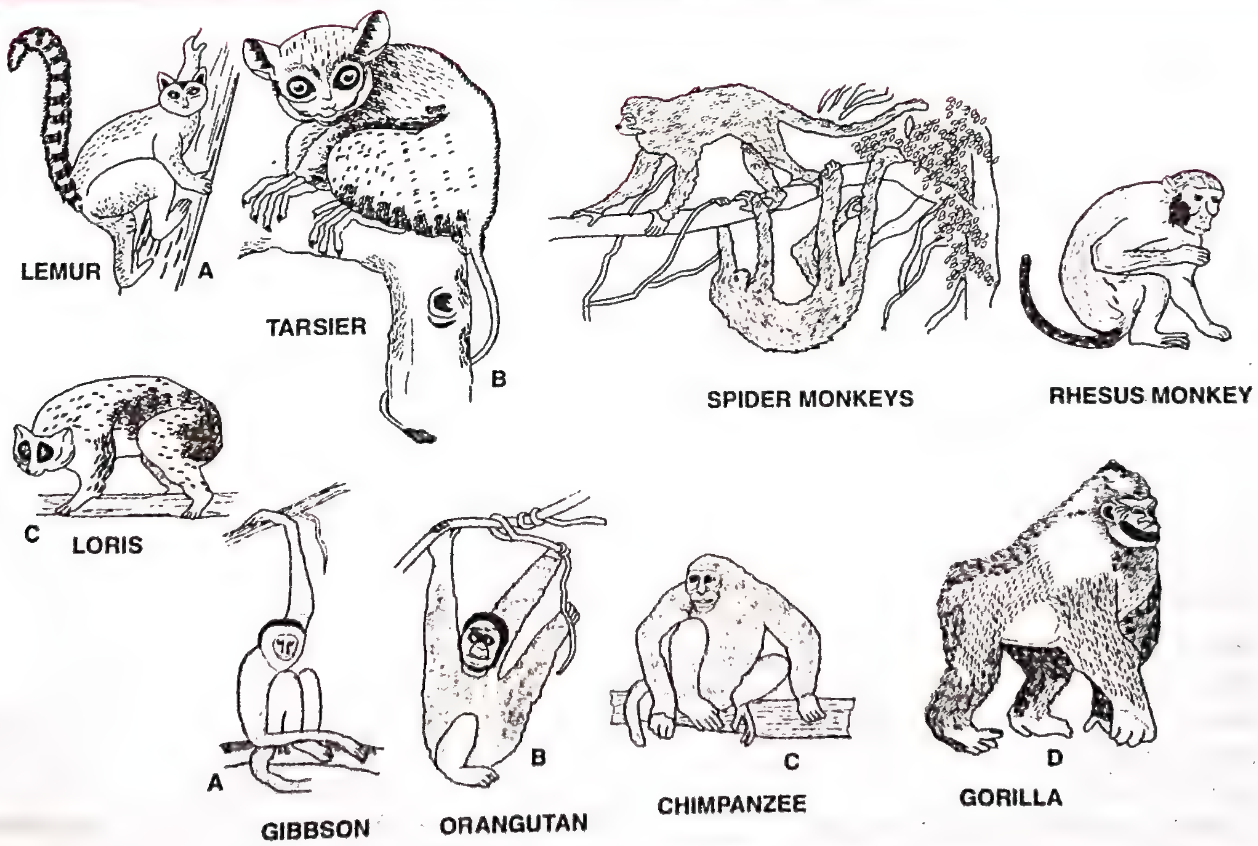


Fig. 4.81. Primates.

ape. It is the only race of apes found in India in the forests of *Assam*. Gibbons have remarkable vocal power. (ii) **Orangutan** (*Pongo or Simia*). It constructs a sort of nest on tree top for living. It is found in Sumatra and Borneo. (iii) **Chimpanzee** (*Pan*). It is the *most intelligent ape*. It is found in Africa. Chimpanzees are the *closest relatives of men*. (iv) **Gorilla** (*Gorilla*). It is the *largest ape*. It is very dangerous. It is found in Africa.

Homo sapiens **(The man)**. The man dominates all the animals and has the following characters. (i) The man is a social and cultured animal. (ii) He is the most intelligent animal who has the ability to learn and transmit experiences. In fact he has a language and speech. (iii) The man has opposable thumbs. (iv) The man has better development of facial gestures.

Differences Between Ape and Man

Ape	*Man*
1. Brow ridges are very prominent.	1. Brow ridges are not so prominent.
2. There is small diastema between incisors and canines.	2. There is no diastema.
3. Arms are longer than the legs.	3. Legs are longer than the arms.
4. Vertebral column has one curve.	4. Vertebral column has four curves.
5. Both pollex (thumb) and hallux (great toe) are opposable.	5. Pollex is opposable hallux is not opposable.
6. Ape is not able to make and use tools, does not have spoken and written language.	6. It has ability to make and use tools, has spoken and written language.

ADDITIONAL INFORMATION

- Slowest mammal— **Three-toed sloth.**
- **Fastest Mammal.** Cheetah
- The **elephant** has 40,000 muscles in its trunk. Not a single bone is found in it.
- **Commonest mammal**— *Homo sapiens* (man)
- Salivary glands are absent in whales and sea cows.
- **Mammals: Largest**— Blue whale, **Tallest** — Giraffe. **Smallest**— Hog-nosed Bat, Pigmy Shrew, **Longest Lived**— Human beings. **Most primitive**— Spiny ant eater, Duck billed platypus.
- **Monkeys: Largest**— Mandrill. **Smallest**— Pygmy marmoset.
- **Largest Ape.** Gorilla.
- **Smallest Ape.** Gibbon.
- **Holocene Epoch**— "Age of Man".
- **Ancon Sheep**— short legged sheep which originated by mutations in a single generation.
- **Fastest growth**— Blue whale.
- Aquatic mammals such as whale, sirenians and seals lack pinna. *Platypus* also does not have pinna.
- **Mammals without 7 cervical vertebrae.** 2-toed sloth (*Choloepus*) with 6 cervical vertebrae, 3-toed sloth (*Bradypus*) with 9, ant bear (*Tamandua*) with 8 and Manatee (*Trichechus*) with 6. *Manatee is like sea cow*.
- Kangaroo rat never drinks water in its entire life.
- Dinosaurs and mammals originated in the same period, *i.e.*, **Triassic period.**
- Origin of Man- **Pliocene Epoch.**
- **Pashmina wool** is obtained from the mountain goat. This animal is found in Ladakh and Tibet.
- **Hangul** (Kashmiri stag, red deer) is the world famous red deer; one of the endangered species of red deer, found in Dachigam National Park situated about 25 km from Srinagar, J & K, India.
- **Land of white Elephant** Thailand.
- **Gaits of Mammals (Types of Feet in Mammals).** Three types of gaits are found in mammals.

1. **Plantigrade.** Entire sole rests on the ground. Examples : bears and men.

2. **Digitigrade Gait.** The animal walks on digits. Examples : dogs, cats, tigers, etc.

3. **Unguligrade Gait.** The animal walks on hoof. Examples : horse, cattle.

- Manatees are the only herbivorous marine mammals.
- **Why did tiger become the national animal of India ?** Tiger has been the national animal of India from 1972. Earlier, from 1969 onwards, this honour was given to the lion because the famous Ashoka Chakra, India's official emblem, has four lions on it. In India however, lions are found in wild state only in Gir forests whereas the tiger is in various states. So the tiger became India's National Animal in 1972. A national scheme called **"Project Tiger"** was launched on Ist April 1973.
- The giant panda represents the emblem of the world wildlife fund.
- Elephant has the longest gestation period.
- Angora wool is obtained from angora rabbits.
- **Snow Leopard** is the state animal of Himachal Pradesh.
- Largest animal of cat family is Panthera tigris.
- **Red Panda** (*Ailurus fulgens*) is found in the Himalayan region, all along Nepal, Sikkim, Upper Myanmar and Southern China.
- National Aquatic Animal of India— **River Dolphin.**
- The wild ass is found in Rann of Kutch, Sikkim, Ladakh and Tibet.
- In India, wild yaks are found in Ladakh and the northern Kumaon hills.
- **Opossum** is a small American and Australian pouched mammal that lives on trees and carries its young in a pouch (a pocket skin on the front of the mother's body).
- **Camel** – State Animal of Rajasthan.

Salient Features of Different Phyla in the Animal Kingdom

Phylum	Level of organisation	Symmetry	Coelom	Segmentation	Digestive system	Circulatory System	Respiratory System	Distinctive Features
Porifera	Cellular	Many	Absent	Absent	Absent	Absent	Absent	Body with pores and canals in walls.
Coelenterata (Cnidaria)	Tissue	Radial	Absent	Absent	Incomplete	Absent	Absent	Cnidoblasts present.
Ctenophora	Tissue	Radial	Absent	Absent	Incomplete	Absent	Absent	Comb plates for locomotion
Platyhelminthes	Organ & organ system	Bilateral	Absent	Absent	Incomplete	Absent	Absent	Flat body, suckers.
Aschelminthes	Organ-system	Bilateral	Pseudo coelomate	Absent	Complete	Absent	Absent	Often worm-shaped, elongated
Annelida	Organ-system	Bilateral	Coelomate	Present	Complete	Present	Present	Body segmentation like rings
Arthropoda	Organ-system	Bilateral	Coelomate	Present	Complete	Present	Present	Exoskeleton of cuticle, jointed appendages
Mollusca	Organ-system	Bilateral	Coelomate	Absent	Complete	Present	Present	External skeleton shell usually present
Echinodermata	Organ-system	Radial	Coelomate	Absent	Complete	Present	Present	Water vascular system, radial symmetry
Hemichordata	Organ-system	Bilateral	Coelomate	Absent	Complete	Present	Present	Worm-like with proboscis collar and trunk

Chordata	Organ-system	Bilateral	Coelomate	Present	Complete	Present	Present	Notochord dorsal hollow nerve cord, gill slits, with limbs or fins

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. What are the difficulties that you would face in classification of animals, if common fundamental features are not taken into account ?

✓ 1. There are numerous animal species which show great variety of life. The various common fundamental characters are taken into account for the classification of these animals. If this has not been done, it is not possible to deal with every living form separately at individual level. Therefore, a classification has to be based on the common fundamental characters to study the diversity properly.

2. The inter relationship among different animals will not be traceable.
3. The picture of all animals at a glance will not be projected.
4. The development of other animal species will not be made.

2. If you are given a specimen, what are the steps that you would follow to classify it ?

✓ These steps are (i) Levels or grades of organisation. (ii) Patterns in organization. (iii) Symmetry (iv) Diploblastic or triploblastic organization. (v) Body cavity and coelom. (vi) Segmentation.

3. How useful is the study of the nature of body cavity and coelom in the classification of animals ?

✓ (i) The body cavity which is derived and lined by mesoderm is called coelom and the animals are called coelomates, *e.g.*, annelids, molluscs, arthropods, echinoderms, hemichordates and chordates. (ii) When the body cavity develops from the blastocoel of the blastula, it is called pseudocoelom and the animals are called pseudocoelomates; *e.g.*, Aschelminthes (round worms). (ii) When the body cavity is not derived from mesoderm, it is called acoelom and such animals are called acoelomates. Examples. porifers, cnidarians, ctenophores and platyhelminthes.

4. Distinguish between intracellular and extracellular digestion ?

✓ Intracellular Digestion	Extracellular Digestion
1. Digestion takes place within the cells.	1. Digestion takes place outside the cell in the alimentary canal.
2. It is comparatively less efficient.	2. This digestion is comparatively more efficient.
3. Only few enzymes are associated with this digestion. Example. *Amoeba*.	3. Large number of digestive glands and enzymes are associated with this digestion. Example. Man

5. What is the difference between direct and indirect development ?

✓ Direct Development	Indirect Development
1. In direct development, the young ones resemble the adults in all respects	1. In indirect development, the young ones do not resemble the adults.
2. There is no intermediate stage.	2. The young ones usually pass through one or more intermediate stages before obtaining the shape of adults.
3. Examples — *Hydra*, Earthworm, Human beings	3. Examples — Silkmoth, House fly, Frog.

6. What are the peculiar features that you find in parasitic platyhelminthes ?

✓ The peculiar features are : (i) Thick tegument (body covering). (ii) Adhesive organs like suckers and the hooks. (iii) Loss of locomotary organs. (iv) In tapeworms, the nutrients are directly absorbed through its body surface (digestive system is absent in this animal). (v) Reproductive system is well developed and they are mostly hermaphrodite. (vi) Mostly anaerobic respiration.

7. What are the reasons that you can think of for the arthropods to constitute the largest group of the animal kingdom ?

✓(i) Tough cuticle for protection. (ii) Presence of striated muscles for quick movements. (iii) Tracheal respiration for direct supply of oxygen as in insects. (iv) Jointed appendages for variety of function.

(v) Nervous system and sense organs are better developed. (vi) Pheromones as found in many insects for communication.

8 Water vascular system is the characteristic of which group of the following ? (a) Porifera (b) Ctenophora (c) Echinodermata (d) Chordata.

✓ (C)

9. "All vertebrates are chordates but all chordates are not vertebrates". Justify the statement.

✓All chordates have a notochord. Chordates include Urochordates, Cephalochordates (both are called protochordates) and vertebrates. In vertebrates notochord is replaced by vertebral column (backbone), however vertebral column is not present in protochordates. Therefore, all vertebrates are chordates but all chordates are not vertebrates.

10. How important is the presence of air bladder in Pisces ?

✓Air bladder regulates buoyancy and helps them in floating in the water. It prevents them from sinking. (ii) Air bladder is present in members of the class Osteichthyes. (iii) Animals of the class Chondrichthyes do not have air bladder and in the absence of air bladder, the animals have to swim constantly to avoid sinking.

11. What are the modifications that are observed in birds that help them fly ?

✓(i) Forelimbs are modified into wings. (ii) Bones are pneumatic, *i.e.*, they have air cavities, to make birds light in weight. (iii) Urinary bladder is absent. (iv) Body is streamlined and offers least resistance while flying. (v) Flight muscles are well-developed.

12. Could the number of eggs or young ones produced by an oviparous and viviparous mother be equal? Why ?

✓ No. In oviparous animals, eggs are laid outside the body of female (in water or land). Some eggs may not get the favourable conditions for development and hatching and may degenerate. To compensate for such losses, many eggs are laid. In viviparous animals the development of embryo occurs inside the mother. Therefore, only one or few young ones could be supported.

13. Segmentation in the body is first observed in which of the following ? (a) Platyhelminthes (b) Aschelminthes (c) Annelida (d) Arthropoda

✓ (c)

14. Match the following

(a)	Operculum	(i)	Ctenophora
(b)	Parapodia	(ii)	Mollusca
(c)	Scales	(iii)	Porifera
(d)	Comb plates	(iv)	Reptillia
(e)	Radula	(v)	Annelida
(f)	Hairs	(vi)	Cyclostomata and chondrichthyes
(g)	Choanocytes	(vii)	Mammalia
(h)	Gill slits	(viii)	Osteichthyes

✓ (a) —(viii), (b) —(v), (c) —(iv), (d) —(i), (e) —(ii), (f) — (vii), (g) —(iii), (h) —(vi)

15. Prepare a list of some animals that are found parasitic on human beings.

✓*Taenia* (Tapeworm), *Ascaris* (Round worm), *Ancylostoma* (Hook worm), *Enterobius* (Pinworm), *Trichuris* (Whip worm), *Wuchereria* (Filarial worm), *Dracunculus* (Guinea worm) and *Pediculus* (Human louse).

TEST QUESTIONS

One Mark Questions (With Answers)

1. Define metamerism.

✓ It is a type of segmentation where external divisions correspond to internal divisions.

2. Define hydrostatic skeleton.

✓ When the coelomic fluid serves as a skeleton it is known as hydrostatic skeleton.

3. What is the main excretory waste in insects ?

✓ Uric acid.

4. Which snake builds a nest ?

✓ The king cobra of India is the only snake in the world that builds a nest.

5. Which teeth are modified into tusks in elephants ?

✓ Two upper incisors

6. How many chambers are there in camel's stomach ?
   ✓ Three chambers (rumen, reticulum, abomasum)
7. Define pneumatic bones ?
   ✓ They have air cavities to reduce weight.
8. Which organ produces voice in birds ?
   ✓ The syrinx
9. Name the cells that line the spongocoel in *Sycon*.
   ✓ Pinacocytes
10. What is bioluminescence ?
   ✓ Bioluminescence is the property of a living organism to emit light.
11. Give two examples of phylum ctenophora.
   ✓ *Pleurobrachia* and *Ctenoplana*
12. Name the phylum where animals have haemoglobin dissolved in the plasma.
   ✓ Phylum Annelida
13. What is the function of parapodia ? Name the animal that has parapodia.
   ✓ Parapodia help in swimming. *Nereis* has parapodia.
14. Name the largest phylum of Kingdom Animalia.
   ✓ Arthropoda is the largest phylum of Kingdom Animalia.
15. Name the excretory organs of (i) insects and (ii) crustaceans.
   ✓ (i) Insects — Malpighian tubules. (ii) Crustaceans — Antennal gland.
16. What is radula ?
   ✓ Radula is a rasping organ for cutting the food in Pila.
17. Name the larvae of (i) urochordates and (ii) cyclostomates.
   ✓ (i) Urochordates — Tadpole (ii) Cyclostomates — Ammocoete.
18. Name the fish that has electric organ.
   ✓ Torpedo
19. Why do cartilaginous fishes have to swim constantly ?
   ✓ Cartilaginous fishes have no swim or air-bladder and to avoid sinking, they have to swim constantly.
20. Name the class of fish where tail fin is heterocoel.
   ✓ Chondrichthyes
21. Name the reptile that has four chambered heart.
   ✓ Crocodile

Two Mark Questions (With Sample Answers)

1. Which features make reptiles successful on land ?
   ✓ (i) Internal fertilization. (ii) The amnion (embryonic membrane) encloses the embryo and provides it with a watery environment during development, therefore, the embryo does not need watery environment (iii) Shell around the egg to check desiccation. (iv) Horny scales on the body of reptiles check loss of water.
2. Enlist the characteristic features of cnidarians which show advancement over poriferans ?
   ✓ 1. Tissue level of organisation. 2. Digestive tract. 3. Nerve cells and sensory cells.

Three Mark Questions (Short Answers Type)

1. How bony fish are different from cartilaginous fish ?
2. Explain the general characters of Reptilia with respect to respiration, excretion and reproduction
3. Write the distinguishing features of Prototheria, Metatheria and Eutheria.
4. Justify the statement "Mammals are the most successful and dominant animals today".
5. Define coelom. Explain the two types of coelom formation in animals.

Five Marks Questions (Long Answers Type)

1. Describe the respiratory organs of nonchordates.
2. Give the general characteristics of the vertebrates and list the distinguishing features of the classes under it.
3. Describe the life history of Anopheles.
4. Give distinguishing characters of phylum Annelida and give five examples of this phylum.

5. Give the special features of phylum Echinodermata. What are the similarities between phylum Echinodermata and phylum chordata.
6. Name three sub-phyla of phylum chordata. Write characters and examples of protochordates.
7. Give the salient features and five examples of class Aves.
8. Describe various modes of asexual reproduction in animals.

Multiple Choice Questions (With Answers)

(1) Which one of the following animals may occupy more than one trophic levels in the same ecosystem at the same time ? (a) Sparrow (b) Lion (c) Goat (d) Frog. *(AIPMT (Mains) 2011)*

(2) Which one of the following have the highest number of species in nature ? (a) Fungi (b) Insects (c) Birds (d) Angiosperms. *(AIPMT (Prelims) 2011)*

(3) Which one of the following groups of animals is correctly matched with its characteristic feature without any exception ? (a) Reptilia : possess 3-chambered heart with an incompletely divided ventricle (b) Chordata : possess a mouth with an upper and a lower jaw (c) Chondrichthyes : possess cartilaginous endoskeleton (d) Mammalia : give birth to young ones. *(AIPMT (Prelims) 2011)*

(4) Which one of the following animals is correctly matched with its particular taxonomic category ? (a) Tiger- *Tigris*, species (b) Cuttlefish-mollusca, class (c) Humans-primata, family (d) Housefly-*Musca*, order. *(AIPMT (Prelims) 2011)*

(5) Which one of the following is categorised as a parasite in true sense ? (a) The female *Anopheles* bites and sucks blood from humans (b) Human foetus developing inside the uterus draws nourishment from the mother (c) head louse living on the human scalp as well as laying eggs on human hair (d) The cuckoo (koel) lays its eggs in crow's nest. *(AIPMT (Prelims) 2011)*

(6) Silk produced by *Antheraea mylitta* is also called (a) Muga silk (b) Tasar silk (c) Eri silk (d) Mysore silk. *(Karanataka CET 2011; WB JEE 2011)*

(7) Pick the mammal with true placenta (a) Kangaroo (b) *Echidna* (c) Platypus (d) Mongoose. *(Karnataka CET 2011)*

(8) Column I contains larval stages and column II contains the groups to which they belong. Match them correctly and choose the right answer.

	Column I		Column II
A	Planula	1.	Annelida
B	Tornaria	2.	Mollusca
C	Trochophore	3.	Arthropoda
D	Bipinnaria	4.	Hemichordata
E	Glochidium	5.	Echinodermata
		6.	Coelenterata

(a) A – 6, B – 4, C – 1, D – 5, E – 2
(b) A – 2, B – 5, C – 1, D – 4, E – 6
(c) A – 5, B – 4, C – 3, D – 2, E – 1
(d) A – 4, B – 3, C – 2, D – 1, E – 5 *(Karnataka CET 2011)*

(9) Animals of class Mammalia have (a) seven cervical vertebrae (b) seven cranial nerves (c) single ventricular chamber (d) fourteen cervical vertebrae. *(J & K CET 2011)*

(10) Secondary body cavity with segmented mesodermal lining is called (a) haemocoel (b) neurocoel (c) true coelom (d) pseudocoelom. *(J & K CET 2011)*

(11) Haemocoel is found in (a) *Hydra* (b) *Pila* (c) earthworm (d) snake. *(Orissa JEE 2011)*

(12) The anterior V-spot in microfilaria of *Wuchereria* represents (a) nerve ring (b) cervical papilla (c) excretory system (d) reproductive system. *(West Bengal JEE 2011)*

(13) The nectar is produced in the flowers which are pollinated by (a) wind (b) water (c) man (d) insects. *(AMU (Medical) 2011)*

(14) National aquatic animal of India is (a) Whale (b) Dolphin (c) Porpoise (d) Seal. *(WB JEE 2012)*

(15) Which one of the following animals possesses giant chromosome ?
(a) *Drosophila* (b) Mouse (c) *Branchiomyces* (d) *Xenopsylla*. *(West Bengal JEE 2012)*

(16) In fish, *Catla catla* the specific name is identical with the generic name, thus it is an example of (a) autonym (b) tautonym (c) synonym (d) homonym. *(AMU 2012)*

(17) Which of the following animals belongs to the phylum mollusca ? (a) Devil fish (b) Dog fish Silver fish (d) Jelly fish. *(AMU 2012)*

(18) Ornithology is the study of (a) birds (b) lizards (c) bryophytes (d) pollen grains. *(Odisha JEE 2012)*

(19) The non-cellular layer present between pinacoderm and choanoderm in body wall of poriferans is known as (a) mesoderm (b) middle lamellae (c) mesenchyme (d) none of these. *(Odisha JEE 2012)*

(20) Which among these is not a homoiotherm ? (a) *Aptenodytes* (b) *Testudo* (c) *Delphinus* (d) *Neophron* (e) *Ornithorhynchus*. *(Kerala PMT 2012)*

(21) Which one of the following pairs of animals are similar to each other pertaining to the feature stated against them ? (a) *Pteropus* and *Ornithorhyncus*-Viviparity (b) Garden lizard and Crocodile – Three chambered heart (c) *Ascaris* and *Ancylostoma* - Metameric segmentation (d) Sea horse and Flying fish - Cold blooded (poikilothermal). *(CBSE PMT Mains 2012)*

(22) Which one of the following options gives the correct categorisation of six animals according to the type of nitrogenous wastes (A, B, C) they give out ?

	A **Ammonotelic**	B **Ureotelic**	C **Uricotelic**
(a)	Pigeon, Humans	Aquatic Amphibia, Lizards	Cockroach, Frog
(b)	Frog, Lizards	Aquatic Amphibia, Humans	Cockroach, Pigeon
(c)	Aquatic Amphibia	Frog, Humans	Pigeon, Lizards, Cockroach
(d)	Aquatic Amphibia	Cockroach, Humans	Frog, Pigeon, Lizards

(CBSE PMT Mains 2012)

(23) Match the name of the animal (Column I), with one characteristics (column II), and the phylum/class (column III) to which it belongs.

	Column I	**Column II**	**Column III**
(1)	*Petromyzon*	ectoparasite	Cyclostomata
(2)	*Ichthyophis*	terrestrial	Reptilia
(3)	*Limulus*	body covered by chitinous exoskeleton	Pisces
(4)	*Adamsia*	radially symmetrical	Porifera

(NEET 2013)

(24) Which of the following are correctly matched with respect to their taxonomic classification? (a) Flying fish, cuttlefish, silverfish-Pisces (b) Centipede, millipede, spider, scorpion-Insecta (c) House fly, butterfly, tsetsefly, silverfish-Insecta (d) Spiny anteater, sea urchin, sea cucumber - Echinodermata. *(NEET 2013)*

(25) One of the representatives of Phylum Arthropoda is (a) cuttlefish (b) silverfish (c) pufferfish (d) flying fish. *(NEET 2013)*

(26) Kokkarebellur Bird Sanctuary is located in (a) Mandya (b) Mysore (c) Chamarajnagar (d) Hassan. *(Karnataka CET 2013)*

(27) Which taxonomic term may be suggested for any rank in the classification? (a) Class (b) Order (c) Species (d) Taxon. *(Karnataka CET 2013)*

(28) Which one of the following groups of 3 animals each is correctly matched with their one characteristic morphological features?

	Animals		**Morphological features**
(a)	Centipede, Prawn, Sea urchin	—	Jointed appendages
(b)	Cockroach, Locust *Taenia*	—	Metameric segmentation
(c)	Scorpion, Spider Cockroach	—	Ventral solid nerve cord
(d)	Liverfluke, Sea anemone, Sea cucumber	—	Bilateral Symmetry

(Karnataka CET 2013)

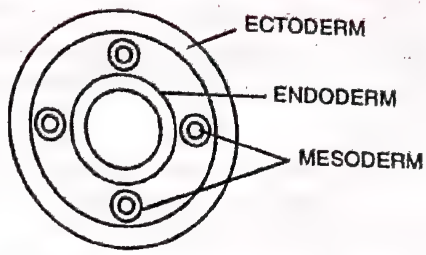
(29) In which of the following phyla the adult shows radial symmetry, while the larva shows bilateral symmetry? (a) Annelids (b) Arthropods (c) Molluscs (d) Echinodermata. *(Karnataka CET 2013)*

(30) Which of the following animals lack alimentary canals (complete digestive systems)? (a) Earthworm (b) Jellyfish (c) Insect (d) Fish. *(AMU Med. 2013)*

(31) Gir Lion Sanctuary Project was started in the year (a) 1976 (b) 1972 (c) 1962 (d) 1952. *(AMU Med. 2013)*

(32) Which of the following is an oviparous mammal? (a) *Balaenoptera* (b) *Delphinus* (c) *Pteropus* (d) *Ornithorhynchus*. *(AMU Med. 2013)*

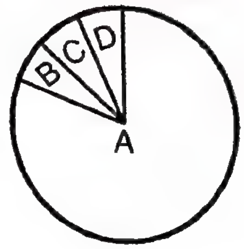
(33) The kind of coelom represented in the diagram given below is characteristic of (a) round worm (b) earth worm (c) tape worm (d) cockroach. (Karnataka CET 2014)



(34) A marine cartilaginous fish that can produce electric current is (a) *Pristis* (b) *Torpedo* (c) *Trygon* (d) *Scoliodon*. (AIPMT 2014)

(35) Given below is the representation of the extent of global diversity of invertebrates. What groups the four portions (A-D) represent repectively?

	A	B	C	D
(a)	Insects	Crustaceans	Other animal groups	Molluscs
(b)	Crustaceans	Insects	Molluscs	Other animal groups
(c)	Molluscs	Other animal groups	Crustaceans	Insects
(d)	Insects	Molluscs	Crustaceans	Other animal groups



(AIPMT 2014)

(36) Functional systems for specific physiological functions are not seen in (a) Annelids (b) Molluscs (c) Arthropods (d) Echinoderms (e) Coelenterates. (Kerala PMT 2014)

(37) Snake, a terrestrial animal that excretes nitrogen wastes in the form of uric acid is called (a) uricotelic (b) ureotelic (c) ammonotelic (d) not confirmed for any type. (J & K CET 2014)

(38) A type of metamorphosis in insects with four developmental stages, *i.e.*, eggs, larva, pupa and adult is (a) heminetabolous (b) paurometabolous (c) holometabolous (d) ametabolous. (AMU 2014)

(39) A jawless fish, which lays eggs in freshwater and whose ammocoetes larvae after metamorphosis return to the ocean is (a) *Eptatretus* (b) *Myxine* (c) *Neomyxine* (d) *Petromyzon*. (CBSE 2015)

(40) Eutrophication of water bodies leading to killing of fishes is mainly due to non-availability of (a) food (b) light (c) essential minerals (d) oxygen. (CBSE 2015)

(41) Metagenesis refers to (a) the presence of different morphic forms (b) alternation of generations between asexual and sexual phases of an organism (c) occurrence of a drastic change in form during post-embryonic development (d) the presence of a segmented body and parthenogenetic mode of reproduction. (CBSE 2015)

(42) Body having meshwork of cells, internal cavities lined with food filtering flagellated cells and indirect development are the characteristics of phylum (a) Coelenterata (b) Porifera (c) Mollusca (d) Protozoa. (CBSE 2015)

(43) Which one of the following animals has two separate circulatory pathways ? (a) Frog (b) Lizard (c) Whale (d) Shark. (CBSE 2015)

(44) Most animals that in deep oceanic water are (a) primary consumers (b) secondary consumers (c) tertiary consumers (d) detritivores. (CBSE 2015)

(45) Coelom is lined on all sides by (a) ectoderm (b) mesoderm (c) endoderm (d) ectoderm and endoderm. (J & K CET 2015)

(46) The ancestors of modern day frogs and salamanders are (a) *Icthyophis* (b) Jawless fish (c) *Amphioxus* (d) Coelacanth. (KCET 2015

(47) Which one of the following matching pairs is wrong ? (a) Mollusca-Pseudocoel (b) Cnidaria-Nematocyst (c) Annelida-Chloragogen cells (d) Echinodermata-Water vascular system. (WB JEE 2015)

(48) Third stage larva of *Wuchereria bancrofti* carried by *Culex* mosquito is called (a) cysticercus (b) merozoite (c) microfilariae (d) trophozoite. (WB JEE 2015)

(49) Most of the cartilages in vertebrate embryo are replaced in adult by (a) blood (b) bones (c) tendons (d) ligaments (e) muscle. (Kerala PMT 2015)

(50) A cuckoo laying eggs in the nest of other species of birds is an example of (a) adelphoparasitism (b) broodparasitism (c) ectoparasitism (d) hyperparasitism. (MH CET 2015)

(51) The marine fish among the following varieties is (a) *Stromateus* (b) *Labeo* (c) *Cirrihina* (d) *Catla*. (MH CET 2015)

(52) This is not a *Cnidarian* (a) *Obelia* (b) jelly fish (c) sea anemone (d) *Beroe*. (Bihar CECE 2015)

(53) Which of the following features is not present in *Periplaneta americana* ?
(a) Indeterminate and radial cleavage during embryonic development (b) Exoskeleton composed of N-acetylglucosamine (c) Metamerically segmented body (d) Schizocoelom as body cavity. *(NEET-I-2016)*

(54) Choose the correct statement. (a) All mammals are viviparous (b) All cyclostomes do not possess jaws and paired fins (c) All reptiles have a three-chambered heart (d) All Pisces have gills covered by an operculum. *(NEET-II-2016)*

(55) Important characteristic that hemicordates share with chordates is (a) ventral tubular nerve cord (b) pharynx with gill slits (c) pharynx without gill slits (d) absence of notochord. *(NEET 2017)*

(56) In case of poriferans, the spongocoel is lined with flagellated cells called (a) oscula (b) choanocytes (c) mesenchymal cells (d) ostia. *(NEET 2017)*

(57) Which of the following represents order of 'Horse' ?
(a) Perissodactyla (b) Caballus (c) Ferus (d) Equidae. *(NEET 2017*

(58) Which among these is the correct combination of aquatic mammals ? (a) Dolphins, Seals, *Trygon* (b) Whales, Dolphins, Seals (c) *Trygon*, Whales, Seals (d) Seals, Dolphins, Sharks. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as
(A) If both **A** and **R** are true and **R** is the correct explanation of **A**.
(B) If both **A** and **R** are true but **R** is not the correct explanation of **A**.
(C) If **A** is true but **R** is false.
(D) If both **A** and **R** are false.

1. **Assertion :** Coral reefs serve as stable marine ecosystems.
   Reason : These are formed by accumulation of debris.
   A B C D
2. **Assertion :** Small Tiedmann's bodies are associated with the ring ambulacral canal in the echi noderms.
   Reason : Tiedmann's bodies contain phagocytes to dispose of the bacteria.
   A B C D
3. **Assertion :** Lateral line system is found in fishes and aquatic larval amphibians.
   Reason : Lateral line system has receptors which are the clusters of sensory cells derived from ectoderm.
   A B C D *(AIIMS 2002)*
4. **Assertion :** Bats and whales are classified as mammals.
   Reason : Bats and whales have four chambered heart.
   A B C D *(AIIMS 2003)*
5. **Assertion :** The duck-billed *Platypus* and the spiny-ant-eater, both are egg-laying animals yet they are grouped under mammals.
   Reason : Both of them have seven cervical vertebrae and 12 pairs of cranial nerves.
   A B C D *(AIIMS 2005)*

ANSWERS

Multiple Choice Questions

(1) —a (2) —b (3) —c (4) —a (5) —c (6) —b (7) —d (8) —a (9) —a (10) —c
(11) —b (12) —c (13) —d (14) —b (15) —a (16) —b (17) —a (18) —a (19) —c (20) —b
(21) —d (22) —c (23) —a (24) —b (25) —b (26) —a (27) —d (28) —c (29) —d (30) —b
(31) —b (32) —d (33) —a (34) —b (35) —d (36) —e (37) —a (38) —c (39) —d (40) —c
(41) —b (42) —b (43) —c (44) —d (45) —b (46) —d (47) —a (48) —c (49) —b (50) —b
(51) —a (52) —d (53) —a (54) —b (55) —b (56) —b (57) —a (58) —b

Assertion and Reason Type Questions

(1) —C (2) —A (3) —B (4) —B (5) —A

Chapter

5

Morphology of Flowering Plants (Angiosperms)

THEORY–a quick rundown

INTRODUCTION TO ANGIOSPERMS

1. **Angiosperms** (Gr. *Angion* = vessel; *sperma* = seed) are flowering, fruit bearing *phanerogamic, spermatophytic, sporophytic* plants. They are the most recent, most advanced, most evolved, most conspicuous and most abundant of all the plants on this earth.

2. Study of flowering plants is called *Anthology.*

3. These plants appeared in lower cretaceous period of mesozoic era about 130 million years back but flourished in Tertiary period of coenozoic era. First flowering plants appeared in Jurassic period and monocots appeared in oligocene period. The **first angiosperm** was *Archaefructus* from mid cretaceous.

4. They lack archegonium which is replaced by pistil (gynaecium). They have **double fertilization** and endosperm of triploid nature. The male gametes are nonmotile and carried by pollen tube (siphonogamy) to avoid dependence on water for fertilization.

5. They comprise about *12500 genera* and *2.68 lakh species out of which 2.20 Lakh are dicots and 50000 are monocots.* Thus dicots are more than 50% of total plants on this earth.

6. They show great diversity in size, form, habit, habitats, life span and mode of nutrition.

7. They are classified into dicotyledons and monocotyledons on the basis of number of cotyledons.

8. Monocots are more advanced than dicots.

9. **Parts of an Angiospermic Plant.** A typical angiosperm or flowering plant has a long plant axis differentitated into underground root system and above ground shoot system. **Root system** comprises roots and their branches. **Shoot system** consists of stem, its branches, leaves, buds, flowers and fruits. The different parts of a plant are called **organs**. Vegetative organs take part in nourishing and fixing the plant, *viz.*, root, stem, leaves. Reproductive organs are required in multiplication. They comprise flowers, fruits and seeds.

10. **Morphology.** (i) **Habitat**. Habitat is the natural home of an organism. Plants are broadly divided into two, terrestrial and aquatic. Aquatic habitats may be fresh water ponds, lakes, rivers and oceans. Only one *Zostera marina* is a marine angiosperm. Fresh water aquatic plants include *Hydrilla, Victoria, Nelumbo* (= *Nelumbium*), *Nymphaea* (Water Lily). In Many aquatic plants, roots are

reduced or absent (*e.g., Utricularia, Wolffia, Ceratophyllum*). **Mangrove** plants grow in saline marshy areas along sea shores (halophytes) *e.g., Rhizophora*. Plant of terrestrial habitats are of two main types– **mesophytes** (moist habitats) and **xerophytes** (dry habitats). Some of the xerophytes store water and mucilage. They are called **succulents** (*e.g., Euphorbia, Opuntia)*. Vegetation occurring at high mountains is called alpine vegetation. Trees do not occur. The limit upto which trees occur is called **timber line.** *Lianas* are woody climbers in tropical forests. (ii) **Habits**. They include appearance, growth patterns and longevity of plants. According to life span (longevity) plants are annual, biennial and perennial.

Ephemeral. A plant that completes its life cycle within 4–6 weeks.

Annuals. Plants complete their life cycle within one season *e.g.*, buttercup, pea. *Wolffia* is smallest rootless annual.

Biennials. Plants complete their life cycle in two seasons— growing vegetatively and storing food in the first season, flowering and fruiting in the second season, *e.g.*, Henbane, Radish (in temperate areas).

Perennials. The plants survive for several years. They may be herbs shrubs or trees *e.g., Canna, Zizyphus*, Mango, *Agave Bambusa, Eucalyptus*, etc. Some perennial plants live for several hundred years, *e.g.*, Sequoia (1500 years), Bodhitree (*Ficus religoisa*) at Gaya. Banyan tree (*Ficus benghalensis*) is almost immortal.

Monocarpic. They are plants which flower and fruit only once in life. All annuals and biennials are monocarpic. Some perennial plants are also monocarpic, *e.g., Agave, Bambusa tulda, Melocanna bambusoides*. They die after bearing fruits.

Polycarpic. They are perennial plants bearing blowers and fruits every year after attaining maturity, *e.g.*, Mango, peepal. Mango shows biennial bearing *i.e.*, one year fruiting is more and in next year, it is poor.

According to texture, height, growth and duration of stems, plants are herbs, shrubs, trees, creepers twiners, climbers and lianas. **Herbs.** Herbs are small plants with soft and pliable stems. **Herbs** can be annual (*e.g.*, Buttercup), biennial (*e.g.*, Henbane) and perennial (*e.g., Canna*).

Shrubs. Shrubs are perennial plants with medium height, woody stems but without any distinction of trunk. Shrubs have oftenly several branches of equal height arising from base and are called **bushes**, *e.g., Capparis*, Rose.

Trees. They are tall perennial plants with a thick woody main stem or trunk. Trees are of three types: (i) **Caudex** (= columnar), unbranched trunk with crown of leaves *e.g.*, Coconut, Palm, Date Palm. A palm like habit is called arborescent. (ii) **Excurrent**. Monopodial with one main stem or trunk from base to apex. Lateral branches giving a cone like appearance, *e.g., Eucalyptus*. (iii) **Deliquescent.** The main stem or trunk is distinguishable only for some distance after which it is replaced by a number of large branches which form a dome-shaped crown *e.g.*, Mango, *Dalbergia, Ficus* (Banyan). *Culm* is unbranched jointed stem with distinct nodes and internodes. Nodes are usually solid while internodes are hollow *e.g.*, Bamboo.

Trailers. They are plants which spread on the ground without rooting at intervals, *e.g., Tribulus terrestris, Euphorbia prostrata*.

Creepers. The plants spread on the ground, rooting at intervals, *e.g.*, Strawberry.

Twiners. They are weak-stemmed plants where the stem coils or twines around an upright support, in dextral or sinistral manner. This coiling is genetic, *e.g., Ipomoea cairica* (Railway Creeper), *Quisqualis (Rangoon Creeper)*.

Climbers. The plants climb up an upright support by special clinging or clasping structures like tendrils, roots and hooks.

Lianas (= Lianes). Woody twiners and climbers are called lianas. They are found in tropical evergreen forests, *e.g., Phanera (= Bauhinia) vahlii, Hiptage.*

Epiphytes. Epiphytes are plants which live on other plants for space only. They are, therefore, also called **space parasites**. Angiospermic epiphytes commonly live on trees, *e.g., Vanda, Dendrobium.* They often possess hanging roots with hygroscopic outer spongy tissue called **velamen** to absorb moisture. *Vanda is first terrestrial and then becomes epiphyte.*

Nutrition

Autotrophic Plants (= Autophytes). The plants are green and able to manufacture their own organic food from inorganic raw materials with the help of chlorophyll and sunlight. Majority of plants are autotrophic.

Heterotrophic plants. They completely or partially obtain their food requirement from outside and are of three types :

1. **Saprophytes:** They are heterotrophic plants which obtain their nourishment from dead decaying organic matter. Angiospermic saprophytes are also called **humus plants**. They are nongreen and bear only scale leaves and take food directly without the help of fungi. True humus plant is orchid *Wullschleigelia aphylla*. Others employ fungi for obtaining nourishment from organic matter and are hence **mycotrophic**, *e.g., Neottia* (Bird's Nest Orchid). *Monotropa* (Indian Pipe), *Corallorhiza* take food from roots of forest plants through fungi.

2. **Parasites.** Parasites are organisms which obtain their nourishment partially or wholly from other living organisms called hosts. Parasites can be external (ectoparasites) or internal (endoparasites), total (holoparasites) or partial (semiparasites), restricted to stem (stem parasites) or root (root parasites) of the host *e.g., Cuscuta* (Dodder), *Cassytha and Arceuthobium* are **total stem parasites**. *Arceuthobium* is the smallest among angiospermic parasite. *Viscum* (Mistletoe) and *Loranthus* are **partial stem parasites**. *These are parasites, epiphytes as well as bear chloroplast. Orobanche* (Broom Rape) on Mustard, Cabbage, Brinjal, Potato and Tomato, *Striga* (on Sorghum and Sugarcane), *Cistanche* (on *Calotropis*), *Balanophora* (on a number of forest trees. *Rafflesia* (bears largest flower of world) 1m diameter and *Sapria* (bears largest flower of India, 0.3 mt diameter) are total root parasites. Sandal (chandan) Wood Tree (*Santalum album) is a* **partial root parasite.** The plant is a small tree which yields fragrant heartwood and is largest parasitic plant.

3. **Carnivorous or Insectivorous Plants.** Carnivorous or insectivorous plants are predators (consumer) as well as autotrophic (producer). They often grow in nitrogen deficient soils. The deficiency is overcome by trapping and digesting small animals/insects, *e.g., Drosera* (Sundew), *Dionaea*, (Venus flytrap), *Utricularia* (bladderwort), *Nepenthes* (pitcher plant) and *Cephalotus (fly catcher).*

Symbiosis. Symbiosis is a mutual relationship between two organisms. It can be positive (mutualism, *commensalism*) or negative *(predation)*.

Symbiotic Nitrogen Fixation. Nitrogen fixing bacteria occur in root nodules of **legumes** (Pea, Gram) or non legumes like *Alnus, Rubus, Casuarina* etc. and even on stem and leaves. The bacteria get shelter and food from the plant. In return, they provide the plant with a major portion of nitrogen fixed by them.

Mycorrhiza. It is a mutually beneficial association between a fungus and the root of higher plants. The fungus absorbs water, salts (from organic matter) and protects the plant from soil borne pathogens. In return, it gets shelter and nourishment from the plant.

Myrmecophily. It is the symbiotic relationship between ants and some higher plants. The ants take food and shelter from the plant and in turn protect the plant from other animals. In *Acacia sphaerocephala* the stipules are hollow for giving shelter to ant. **Leaflet tips** (Belt's corpuscles) and rachis (extra floral nectaries) possess proteinaceous feeding materials for ants.

ROOT

Root is generally non-green, underground, **positively geotropic** (only main root), **positively hydrotropic** and often **negatively phototropic** descending cylindrical axis of the plant body which develops from *radicle* of the embryo. It is without nodes, internodes, leaves, buds, flowers and fruits. Root posseses a root cap (at its tip) and fine thread like **root hairs** (in subapical region). Root branches are **endogenous** (*stellar*) in origin (developing from pericycle) between two protoxylem points.

Vascular bundles are radial. Roots primarily help in fixation (anchorage) of the plant, absorption of water and mineral salts from the soil, conduction of absorbed water and minerals to the stem and soil binding. Roots also do secondary functions of respiration, floatation, photosynthesis, climbing, storage reproductory, extra support etc.

Parts of a Root

In a typical root, there are five distinctive zones starting from apex to the base.

1. **Root Cap** (Calyptra). It is a cap like covering over the root tip for protection against friction from soil particles. It is derived from calyptrogen. Root cap being rich in starch grains responsible for geotropic response (graviperception). **Multiple,** multilayered, multicellular root cap occurs in the aerial root of *Pandanus* (Screw Pine, Keora). Aquatic roots often possess root pockets instead of root caps *e.g., Eichhornia Lemna, Pistia*. They are non-renewable and function as balancers. **Root cap is absent in epiphytes, parasites and hydrophytes and mycorrhizal roots.**

2. **Growing Point** (Meristematic zone). It is hardly 1mm long region of meristematic cells. The growing point produces new cells for root cap and basal parts. It is, therefore, the **zone of cell division/mycorrhizal formation**. The cells are thin and nonvacuolated.

3. **Zone of Elongation.** It is 4–8 mm long portion behind the tip. Here cells elongate rapidly due to vacuolisation. The zone is responsible for growing of root in length.

4. **Root Hair Zone.** The region is 1–6 cm long. Xylem and phloem differentiate here (hence cell maturation zone). Outer cells of area just above the region of elongation give rise to tubular un-branched unicellular **root hairs** for increasing absorptive area. **Root hairs are absent in parasitic and mycorrhizal roots.**

5. **Zone of Mature cells.** Bulk of the root is made of it.

The region of fastest growth is behind the root tip. Growth tip shows growth in 2 directions opposite to each other.

ROOT SYSTEM

A complex of one type of roots and their branches is called root system. It is of two types namely tap root system and adventitious root system.

Tap Root System

It is a system of roots formed by tap root and its branches. **Tap root** is the **primary root** which develops from the elongation of the radicle of embryo and persists throughout the life of plant. It is first formed root and grows vertically downwards. It bears horizontal or obliquely oriented secondary roots (branches of first order) in an **acropetal succession.** Secondary roots bear tertiary roots acropetally. Tertiary roots are oriented in different directions. Final root branches are called **rootlets.** *They bear root caps and root hairs.*

Tap root system is of two types ; (i) **Deep Feeder** or **Recemose tap root system** in which primary or tap root is long with comparatively shorter branches, *e.g.*, Mango, Peepal. (ii) **Cymose or**

Surface Feeder tap root system. Wherein the tap root is short while the secondary roots are long, spreading below the soil surface, *e.g.*, *Solanum nigrum*.

Modifications of Tap Root System

To perform some secondary functions, roots undergo modifications. They are identified as tap root due to their origin from radicle and bearing root hairs.

1. **Fleshy/storage Tap Roots.** Tap roots become swollen due to storage of food. Hypocotyl may also become enlarged and swollen. Secondary roots are thin and thread-like. They do not occur in the region of hypocotyl. These roots arise singly. The leaves are radical as they appear to arise from root directly.

(i) **Conical.** Fleshy root is like a cone, being thickest towards the base (soil surface) and gradually tapering towards apex. Thread like secondary roots are found throughout the length of the root showing that fleshy part is *tap* root *e.g.*, Carrot.

(ii) **Fusiform.** The root is swollen like a spindle, being thickest in the middle and narrowing towards both apex and base. In Indian Radish only the base is formed of swollen hypocotyl. In English Radish the basal half is swollen hypocotyl while the apical half is swollen enlarged tap root *i.e.*, edible part is formed by hypcotyle and tap root both. Here less than 2/3rd part of root is formed by hypocotyl. Secondary roots develop from the tap root part only.

(iii) **Napiform** is like a 'top' or sphere that thins out abruptly at the apex. In Turnip, the swollen part is hypocotyl. In **beet** chakundar/red root the swollen part is formed jointly by hypocotyl and tap root. Secondary roots occur in tap root part. More than 2/3rd part of fleshy root is formed by hypocotyl.

(iv) **Tuberous.** Tap root is thickened except at the base without producing a definite shape, *e.g.*, *Mirabilis*.

2. **Nodulated (Tuberculated roots).** In legumes (*e.g., Pisum sativum, Cicer arietinum)* the roots bear numerous irregular swellings called **nodules** or **tubercles**. The nodules are pinkish and contain nitrogen fixing bacteria *Rhizobium*. Both bacteria and legume are benefitted by this association called **reciprocal symbiosis**. Due to it legumes are rich in proteins and are used in crop rotation. Nodules are pinkish due to a pigment leghaemoglobin which carry oxygen and provide anaerobic environment in nodules for nitrogenase to fix nitrogen. These nodules are found on primary and secondary roots only.

3. **Pneumatophores.** Pneumatophores or **respiratory roots** are short, vertical and negatively geotropical (*apogeotropic)* roots which occur in *mangrove plants* (Halophytes of swampy saline areas near sea shores). The roots come out of swamp. Their upper ends bear lenticels (pneumathodes) for exchange of gases, *e.g., Avicennia, Sonneratia, Heritiera.* *

4. **Buttress Roots.** They are laterally compressed horizontal roots which travel along the ground for some distance and provide extra mechanical support *e.g., Ficus elastica* (Rubber Tree), *Ficus religiosa* (Peepal), *Bombax* (Simbal). These roots are formed jointly by base of trunk and tap root.

5. **Reproductive Roots.** Some tap roots or their branches develop adventitious buds and help in vegetative reproduction, *e.g., Dalbergia, Populus.*

6. **Mycorrhizal roots.** These roots of higher plants possess fungal hyphae (live symbiotically) which help them to absorb food as well protection against other fungi. Root hairs are absent. Fungal hyphae may act as root hairs *e.g., Pinus, Betula.*

Adventitious Root System

It is a complex formed by roots that develop from any parts of the plant other than radicle/primary

root or its branches. **These roots are common in monocots and pteridophytes** and are not deep rooted. These roots do not have root cap and root hairs.

1. **Fibrous Roots.** They are thin thread-like adventitious roots which often develop in groups. Fibrous roots provide better and firm anchorage to the plant, *e.g.*, Grass, Wheat.

2. **Fleshy Adventitious Roots.** Adventitious roots are swollen due to storage of food. Few examples of such roots are:

(i) **Root Tubers or Tuberous or Tubercular roots.** Swollen roots of no definite shape and occur singly. They arise from node of creeping stem, *e.g.*, *Ipomoea batatas* (Sweet Potato), Tapioca (Cassava).

(ii) **Fasciculated Roots.** Swollen adventitious roots of definite shape that occur in groups or fascicles, and arise from base of stem, *e.g.*, *Asparagus* (at intervals), *Dahlia* (at stem base).

(iii) **Palmate Roots.** Fleshy root is branched giving the appearance of a human hand, *e.g.*, *Orchis*.

(iv) **Nodulose Roots.** The adventitious roots are swollen at their tips, *e.g.*, *Curcuma amada* (Mango Ginger),

(v) **Moniliform or Beaded Roots.** The fleshy roots give a beaded apperance, *e.g.*, (Bitter gourd) *Momordica*, *Portulaca*, some grasses.

(iv) **Annulated Roots.** The roots bear series of ring-like swellings, *e.g.*, *Ipecac*.

3. **Prop or Pillar or Columnar Roots.** They are **piller-like** roots which give extra mechanical support to heavy stem branches, *e.g.*, Banyan Tree. Here the young prop adventitous roots arise from the horizontal branches of stem and hang in the air. They are hygroscopic also and help in absorbing water from air young condition. They appear red on absorption of water. *Rhizophora*, a mangrove plant, also develops prop roots. These prop roots possess lenticels for aeration. Prop roots of Banyan tree helped it to spread in an area of 200 acre in Indian Botanic Garden, Sibpur, Hawrah. This single banyan tree had 1600 prop roots. The largest banyan tree is recorded from Andhra Pradesh.

4. **Stilt Roots (Brace Roots).** They are stout/oblique roots which arise in circular whorls from the lower nodes of the stem. They grow **obliquely** downwards into the soil, develop fibrous roots and give extra support to the long unbranched stem, like supporting wires of a tall T.V. antenna pipe, *e.g.*, *Maize*, *Sorghum*, Sugarcane. These roots are in addition to the normal fibrous adventitious roots of the plants. In *Pandanus* (Screw Pine) supporting stilt roots develop from the lower surface of the oblique stem. These roots possess multiple multilayered multicellular caps. Stilt roots do not absorb water.

5. **Haustorial or Parasitic Roots or Sucking Roots.** The adventitious roots arise from climbing stem and penetrate the host to take nutrition *e.g.*, *Cuscuta* (Amarbel/Dodder), *Viscum* (Mistletoe). In *Cuscuta* these roots make connection with xylem and phloem of host to absorb water and food both. In *Viscum* that has chlorophyll, these roots make connection with xylem of host to take water and minerals only.

6. **Clinging or Climbing Roots.** The adventitious roots help the weak plant in climbing by penetrating the fissures or cracks of the support. These roots arise from node *e.g.*, Betel (*Piper betle*), Black Pepper (*Piper nigrum*), Money Plant (*Pothos*), Ivy (*Hedera*). *Tecoma* or internode or both as in *Hedera* (Ivy). In *Tecoma* these are claw like. These roots secrete a sticky juice which on drying stick the plant to subrtratum. *Orchids also bear clinging roots in addition to epiphytic roots.*

7. **Photosynthetic or Assimilatory Roots.** They are green roots which take part in photosynthesis, *e.g.*, *Tinospora*, (climber), *Podostemon* (a shallow water hydrophytic plantless root) bearing haptera for fixation, *Taeniophyllum* (leafless angiosperm) *Trapa*. In *Trapa* (*Shingara*) the photosynthetic roots are highly branched. Some workers consider them to be submerged leaves.

8. **Epiphytic Hygroscopic Roots.** The roots are found in epiphytes/orchids. They arise from base of stem and hang in the air and possess **velamen** or spongy tissue for absorbing moisture directly from atmosphere. The epiphytic roots are devoid of root hairs and root caps. They are green and assimilatory also *e.g.*, *Vanda*, *Dendrobium*. Velamen is a dead spongy tissue of empty cells. It absorbs water present on the surface of these roots.

9. **Epiphyllous Roots.** The roots develop from leaves, especially the injured parts, *e.g.*, *Bryophyllum*, *Begonia*.

10. **Floating Roots.** The roots are white spongy and arise from node stem and store air. They help the aquatic plants to remain on the surface of water *i.e.*, floatation as well as in breathing also *e.g.*, *Jussiaea* (= *Ludwigia*).

11. **Root Thorns.** In certain plants, some of the roots are modified into hard pointed structures called thorns and spines *e.g.*, *Acanthorhiza*, *Inartea exorhiza*.

12. **Contractile Roots.** The roots are glucose rich and turgid and can shrink to bring an underground organ to its proper depth, *e.g.*, corm in *Crocus (Kesar)* and *Freesia*.

13. **Leaf Roots.** In floating fern *Salvinia*, one leaf of each node is modified into a bunch of roots for balancing the aquatic plant in water.

14. **Reproductive Roots.** The adventitious roots may develop adventitious buds and help in vegetative propagation, *e.g.*, *Dahlia*, Sweet Potato (*Ipomoea batatas*).

STEM

Stem is ascending cylindrical axis of plant body which develops from the plumule of the embryo and grows by means of terminal bud. It is positively phototropic, negatively geotropic and negatively hydrotropic. It bears nodes and internodes buds, leaves, flowers, fruits and seeds. Hair, when present, are generally multicellular. Stem branches are **exogenous** in origin (from surface meristem in the cortex). Stem with its branches, leaves, buds and flowers form shoot system. The main function of stem is to properly spread out these organs for their specific functions. It also helps in conduction of water and salts, photosynthesis and provide support to branches.

Buds

Bud is a condensed, undeveloped, compact embryonic shoot having a growing point covered with crowded overlapping immature leaves. Buds arise exogenously from epidermis. Buds are of several types.

(A) *According to Nature*

(1) **Vegetative buds.** They buds produce leafy shoots.

(2) **Floral buds.** They are reproductive buds and produce flowers.

(3) **Mixed buds.** Produce both leafy and floral shoots.

(B) *On the basis of Position*

(1) **Terminal buds.** Terminal or apical buds occur at the tip of the stems and their branches. Terminal buds are responsible for primary growth in length.

(2) **Lateral buds.** The buds are found at positions other than apex. These buds are of four types :

(a) **Axillary buds.** The buds develop in the axil of leaves and produce branches. (b) **Accessory buds.** They are additional buds borne at the leaf bases. Accessory buds are of two kinds : (i) **Collateral buds.** Present on the side of axillary bud, *e.g.*, lilies. (ii) **Superposed buds.** Present

above the axillary bud, *e.g., Aristolochia*. (c) **Extra-axillary buds**. These buds develop on the node but outside the leaf base. (d) **Adventitious buds**. These buds are formed at place other than nodes. Depending upon the organ on which they are borne, the adventitious buds are called **foliar** (on the leaf *e.g., Bryophyllum, Bigonia*), **cauline** (on stem, outside node, *e.g.*, Rose) and **radical** (on the roots), *e.g.*, root of *Dalbergia* (shisham).

(C) *On the basis of Activity :* Buds are :

(1) **Active buds.**

(2) **Dormant buds** which remain dormant for shorter or longer periods.

(D) *On the basis of Covering.*

Buds are either **covered buds,** (Buds surrounded by hair, scales etc.) or **naked buds,** *i.e.*, buds without covering that are **common in tropical plants.**

Modifications of Buds

(a) **Bulbils** are fleshy vegetative buds which store food and take part in vegetative propagation. Bulbils can be radical (*e.g., Oxalis* – base of swollen root), floral (*e.g., Agave*, Onion), foliar (*e.g., Cardamine*) or axillary (*e.g.*, Lily, *Dioscorea)*. Bulbils of *Agave* germinate while still attached on inflorescence and thus show vivipary. (b) **Cabbage** represents the largest apical bud. It is a vegetative bud and stores food. Vegetative buds, are also quite large in Brussel's sprout or lettuce head. (c) **Turions** are fleshy perennating buds in hydrophytes. (d) **Buds** are modified into tendrils (*Cucurbita, Passiflora*), thorns (*e.g., Duranta*).

Stem Branching

The pattern of arrangement of branches on stem is called branching. It provides proper place for each branch. Unbranched stem is called *Caudex* (= Columnar). Caudex is unbranched stout stem with scars and remnants of fallen leaves and crown of leaves *e.g.*, palms. *Culm* is that caudex in which nodes and internodes are very well distinct (jointed stem). Nodes are solid and internodes hollow. Such culms are called *wooden grasses e.g.*, Bamboos.

Branching is of two types :

(i) *Dichotomous :* The growing point divides into two to form two similar branches *e.g.*, liverworts, *Dictyota, Asclepias, Hyphaena.*

(ii) *Lateral* : Axillary buds form a lateral branch and apical bud remains non dividing. Branches develop from lateral buds in two manners.

(a) **Racemose or Monopodial Branching.** Apical bud of the main stem grows indefinitely so that the main axis continues from base to the tip. This unbranched axis is called monopodial axis or trunk. Lateral branches do not compete with the main axis. They develop **acropetally** (oldest towards the base and youngest towards the growing point). It gives pyramidal (excurrent) shape. *e.g., Eucalyptus, Polyalthia*, Mustard, *Casuarina, Pinus.*

(b) **Cymose or sympodial Branching**. Apical bud of the main stem has limited growth. It is then either used up or modified into a flower/thorn/tendril. Further growth of axis is continued by one, two or more branches arising from axillary buds. Thus main axis is not produced by the activity of main apical bud but by many axillary buds, hence called sympodial axis (sympodium). Accordingly, cymose branching is of three types :

(1) **Uniparous or Monochasial Cyme**. The terminal bud stops its activity or get modified into the flower/tendril/thorn. Further growth of the axis is continued by one axillary branch arising laterally from axillary bud. Soon its bud also stops growth and the process is repeated. The successive branches develop on either both the sides alternately (*scorpioid, e.g.*, Grapevine) or on one side only (*helicoid, e.g., Saraca*).

(2) **Biparous or Dichasial Cyme.** After the inactivity of the growing point of the parent axis, further growth is continued by two lateral (axillary) branches. Axis is multipodial, *e.g.*, *Viscum, Carissa, Mirabilis, Datura.*

(3) **Multiparous or Polychasial Cyme.** After the inactivity of the growing point of the parent axis, further gorwth is continued by more than two lateral branches. Axis is **multipodial**, *e.g.*, *Euphorbia helioscopia, E. tirucalli, Croton.*

Forms of Stem

Stems are of three types – aerial, subaerial and underground.

(1) **Aerial or Epiterranean Stems. Stem is above the ground.** It may be

(A) **Reduced.** Reduced stem is like a green disc in Radish, Carrot and Turnip. It bears radical leaves. In *Lemna* and *Wolffia* the reduced stem is green and flattened to help in floating. In bulb (*e.g.*, Onion, Garlic) the reduced stem is a non-green disc.

(B) **Erect.** The stem is vertical and sufficiently strong to stand erect.

(C) **Weak.** The stem is soft, weak. It requires a support. Weak stem can be upright or prostrate.

(1) **Upright Weak Stems.** They are those weak stems which grow upright with the help of support, *e.g.*, twiners and climbers.

(i) **Twiners.** They are weak stemmed plants where the stem coils or twines around an upright support. Clinging organs are absent. Direction of coiling around the support is *specific and genetically determined.* It can be **sinistrose** (coiling is anticlockwise, *e.g.*, *Convolvulus, Ipomoea)* or **dextrorse** (Clockwise, *e.g.*, Bean, *Asparagus).* This coiling is due to *nutation.*

(ii) **Climbers.** The weak stem plants rise up with the help of some clinging or coiling structures. climbers are of the following kinds : (a) **Tendril climbers.** Tendrils are narrow thread-like green sensitive structures which coil around the support and help the plant to cling and climb. Tendrils can be modifications of stem or leaf. (b) **Root climbers.** Adventitious roots function as clinging or clasping organs in *Piper* (Betel, Pepper), *Tecoma*, Ivy, Pothos (money plant). (c) **Scramblers.** The climbers cling to the support by means of hard structures like prickles (*e.g.*, climbing roses), spines (*e.g.*, climbing *Asparagus*), curved thorns (*e.g.*, *Bougainvillea*), flora/inflorescence stalk hooks (*e.g.*, *Artabotrys*) or leaflet hooks (*e.g.*, *Bignonia unguis-cati).*

(2) Prostrate Weak Stems (Subaerial Weak Stems/Subepiterranean stems). The weak stems take the support of ground for spreading. They are of four types :

(i) **Trailers (Stragglers).** The shoots spread over the ground without rooting at intervals. They are fixed at one point by tap root and do not produce daughter plants, *e.g.*, *Euphorbia prostrata.* Trailers are of two kinds, **procumbent** (trailing branches flat prostrate, *e.g.*, *Tribulus, Evolvulus*) and **decumbent** (some trailing branches rise at its apex, *e.g.*, *Tridax, Portulaca*)

(ii) **Runners.** Runners are special , narrow, green, horizontal branches which develop from an axillary bud, creep on the ground and root at intervals where new crowns are also formed due to which grasses show vigrous and quick growth, *e.g.*, Lawn Grass, *Oxalis, Centella.* In *Lawn grass, vigrous and quick growth is due to runner.* A runner is actually a series of plants of successive vegetative *generation.* Roots are adventitious.

(iii) **Stolons.** They are special above ground (*e.g.*, Strawberry) or underground (*e.g.*, *Colocasia*) horizontal branches which develop at the base of a crown, can arch over small obstacles, root at intervals and form new crowns.

The stolon is called a long distance runner with longer and thicker internodes. When branches spread out in all directions on ground, it is called *diffuse stolon.*

(vi) Offsets. They are **one internode long thick, short runners** formed in rosette plants at ground or water level and in the axil of leaf *e.g.*, Water Lettuce (*Pistia*), Water Hyacinth (*Eichhornia*) *offset is also found in some xerophytes like Agave.*

(3) Underground Stems. Underground or subterranean stems are nongreen like roots but differ from the latter in (i) absence of root cap and root hair (ii) presence of terminal bud, nodes and internodes, occurrence of leaves (scale or foliage) on the nodes and exogenous branching. These store reserve food and can be used as seeds to produce new plant. They also help in perennation and vegetative propagation. Underground stems are of the following five types :

(i) Sucker. It is a non-green narrow stem which develops at the underground base of a crown, grows horizontally for some distance and then comes out obliquely to form a new crown *e.g., Chrysanthemum, Mentha* (Mint). In mint the horizontal branches some time appear as runners. Banana possesses underground sucker-like structures called **(sword suckers)** for formation fo new leafy trunk.

(ii) Rhizome. It is an underground indefinitely growing perennial main stem which gives rise to annual aerial branches or leaves under favourable conditions. It has nodes and internodes. On nodes are present brown scale leaves (cataphylls) and bud in the axil of scale leaves as well as at apex. It is of two types *viz.*, (a) **Rootstock rhizome** is oblique or vertical with tip almost reaching the soil surface. It is often unbranched (*exception Banana*), *e.g.*, fern *Dryopteris*, Bomboo, *Alocasia*, Banana, Aroids (b) **Straggling rhizome** creeps **horizontally** in the soil. It is often branched. Branching may be *sympodial* (uniparous cyme, *e.g.*, Ginger Turmeric, Canna) or *monopodial* (racemose *e.g., Saccharum, Nelumbo*). Rhizome is diageotropic.

(iii) Corm. It is annual, **vertically** growing thick, condensed swollen, spherical or subspherical underground stem which bears circular nodes, sheathing leaf bases and scale leaves. Buds present externally on corms give rise to new aerial shoots and new corms, *e.g., Colocasia, Fresia, Croocus* (saffron), *Amorphophallus* (Zamikand; Elephant Foot), *Colchicum, Gladiolus*. Stem is enlarged in corm. It is actually whole stem. Corm is called *solid bulb*. It is *vertical root stock (rhizome) with large apical bud.*

(iv) Bulb. It is an **underground condensed shoot** having reduced discoid stem (acaulescent), fleshy scales (Leaf bases), internal buds and adventitious roots. Bulb is an underground modified bud. Bulbs are of two types : (a) **Tunicated layered bulb**. The fleshy scales are arranged in concentric manner. A tunic or dry membranous scale is present on the outside. It is either (1) **Simple tunicated bulb** *e.g.*, Onion. In onion food stored in Leaf bases is glucose. (2) **Compound tunicated bulb** *e.g.*, Garlic Garlic contains a number of sickle-shaped **bulblets or cloves** covered by tunics. Each bulblet or clove is actually a bud as it arises in the axil of a tunicated leaf. It is also covered by a tunic. (b) **Scaly bulb**. The fleshy scales overlap one another only on the margins. It is, therefore, also called **loose bulb**. A tunic is absent in the bulb of Lily.

(v) Stem Tubers. They are swollen tips of underground branches (called **stolons**). Each tuber has a number of **eyes** (nodes) each with a leaf scar or ridge and 3 buds (one axillary and 2 accessory). *Thus eye represents node and axillary buds.* Eyes are more towards distal end where terminal bud is present. This end is called rose end. The skin has corky covering with lenticels. Eye represents seed as it can form new plant, *e.g.*, Potato (*Solanum tuberosum*), Jerusalem Artichoke (*Helianthus tuberosus*). It is the only underground stem that is without adventitious roots. Reserve food in Jerusalem artichoke is inulin. In Chinese Artichoke (*Stachys*) it is stachyose.

Aerial Stem Modifications

These modifications by providing support and protection.

1. **Stem Tendrils.** They may be branched with scale leaves in the region of branching :

(i) **Axillary** arising from axillary bud e.g., *Passiflora* ; (ii) **Extra-axillary**, arising from extra axillary bud e.g., *Luffa*, *Cucurbita* ; (iii) **Scorpioid Stem Tendrils** arising from apical bud and then become leaf opposed e.g., *Vitis vinifera* (Grape Vine). (iv) **Floral Bud/Inflorescene Tendrils**, *e.g.*, *Antigonon*.

2. **Stem Thorns.** They are stiff sharp structures which are formed for reducing transpiration and protection from animals. Thorns are generally axillary *e.g.*, *Citrus*, Pomegranate, *Bougainvillea*. In *Duranta* the thorns bear small leaves. In *Alhagi* the thorns bear flowers. In *Carissa* (karonda), apical bud forms thorns. In Ulex stem thorns and leaf spines both are present. In *Artabotrys*, curved hooks are borne on pedicel for climbing.

3. **Phylloclades.** They are green, photosynthetic, often succulent stems of indefinite growth. The leaves are caducous. Phylloclade formation is an adaptation to dry habitats, *e.g.*, *Euphorbia royleana*, *E. tirucalli*, *Casuarina*, *Epiphyllum*, *Muhlenbeckia* (= *Cocoloba*), *Opuntia*. In *Opuntia* each segment or phylloclade represents a branch that arises in the axil of a caducous leaf and possesses raised areas or areoles representing nodes. An areole has a leaf scar, one or two spines and a number of stiff siliceous hair called **bristles** or **glochidia**.

4. **Cladodes** (Cladophylls). They are green photosynthetic stems of limited growth (generally one internode long) with leaves reduced to scales or modified into spines, *e.g.*, *Ruscus*, *Asparagus*. Cladodes of *Ruscus* are leaf like, borne in the axils of scale leaves, having a floral bud and scale leaf in the middle (therefore, upper half leaf, lower half stem). In *Asparagus* the cladodes are needle like and develop in clusters.

Lemna has smallest cladode.

LEAF

A leaf is green, dorsoventrally flattened, **exogenous** lateral outgrowth that arises from the node of the stem or its branch. Leaf functions for transpiration and gaseous exchange during respiration and photosynthesis. Leaf develops from shoot meristem as Leaf primordia. Its growth is limited as it grows by intercalary mesistem that is consumed during growth.

Types of Leaves

Green leaves of the plant are called **foliage leaves**. Nongreen membranous thin leaves are known as **scale leaves** (cataphylls). Floral appendages like sepals, petals, stamens, carpels are called **floral leaves**. The leaves bearing spores or sporangia are named **sporophylls**. The bract (hypsophyll) is a small leaf like structure which bears floral bud in its axil. **Cotyledons** are leaves borne by embryo in the seed. **Prophylls** are the first 1–2 leaves of a branch which are generally different from others. *Epicalyx* represent extra whorl of bracteoles and present in some flowers like *Hibiscus* (shoe flower).

Leaf Insertion

Leaves are of three types: 1. **Radical***. Leaves borne at the ground level from a reduced stem, *e.g.*, Radish. 2. **Cauline**. Leaves borne on the main stem, *e.g.*, Maize. 3. **Ramal**. Leaves borne on branches, *e.g.*, *Zizyphus*.

Parts of a Leaf (Phyllopodium)

A typical leaf has three basic parts :

(i) **Leaf Base (Hypopodium).** It is the point by which the leaf is attached to the stem. It is made up of **stem cells**. A swollen leaf base is called **pulvinus**, *e.g.*, legumes. This pulvinus leaf base acts

* Radicle is part of embryo, represents future root. Radical is Leaf insertion.

as **motor organ** and stores K^+ ions and is responsible for *sleep movements/shock movements.* In monocots, the leaf base is sheathing or encircling the stem, *viz.*, **amplexicaul** (enclosing the stem completely, *e.g.*, Wheat. Grasses) and **semi-amplexicaul** (enclosing the stem half-way). Leaf base may bear two lateral outgrowths called **stipules**. Leaves with stipules are called **stipulate** while the ones devoid of stipules are called **exstipulate**. Some leaves bear an outgrowth or **ligule** between leaf base and lamina. They are called **ligulate,** *e.g.*, grasses.

(ii) Petiole (Mesopodium). It is leaf stalk. It is *developed in the last during development of leaf.* A leaf with a petiole is called **petiolate**. A **subsessile** leaf has a small petiole while a **sessile** leaf is without a petiole. Petiole is **winged** in *Citrus* and Sweet Pea, **tendrillar** in Garden Nasturtium, *Nepenthes, Clematis*, **spongy** and inflated with aerenchyma in *Eichhornia* (water hyacinth) and converted into **phyllode** in Australian species of *Acacia*.

(iii) Lamina (Epipodium). Lamina or **leaf blade** is the terminal thin usually flattened green photosynthetic part of the leaf. Its upper (= ventral) surface is called **adaxial** while lower (dorsal) surface is **abaxial.**

Stipules

Stipules are two lateral outgrowths of the leaf base in many dicots but never in monocots. They can be: (i) **Free Lateral Stipules**, *e.g.*, Shoe Flower (China Rose) (ii) **Scaly Stipules**, *e.g., Cassia fistula* (iii) **Adnate** (petiolar) fused with petiole, *e.g.*, Rose, Ground nut, (iv) **Ochreate** (fused to form sheath or **ochrea** around the stem), *e.g., Polygonum*, (v) **Interpetiolar** (Stipules of opposite leaves fused to appear in between their petioles), *e.g.*, Kadam (vi) **Foliaceous** (Leafy) *e.g.*, Wild pea (*Lathyrus aphaca)*, Pea (vii) **Bud Scales** (protective scales) stipule of young leaves connate to protect bud *e.g., Ficus*/Rubber plant where stipules are red in colour, Banyan) (viii) **Stipular Spines**, *e.g.*, *Acacia, Zizyphus, Capparis* (xi) **Stipular Tendrils**, *e.g., Smilax.*

Stipels are stipules at the base of leaflets of compound leaves *e.g.,* Bean.

Stipules protect the leaf and its axillary bud in young state or on modification function for defense (spines), support (tendrils) or photosynthesis (foliaceous).

Leaf Duration

1. **Caducous**. Falling off soon after their formation, *e.g., Opuntia.*

2. **Deciduous** (Annual). Falling off under unfavourable conditions or at the end of growing season *e.g.*, Mulberry, Poplar.

3. **Persistent** (Evergreen). Leaves remain on the plant for more than one year, fall off individually at different times so that the plant gives an evergreen look *e.g., Eucalyptus.* It helps to remove waste through old leaves.

Phyllotaxy (Phyllotaxis)

The mode of **arrangement of mature leaves** on the stem or its branches is called phyllotaxy. Its object is to expose every leaf in light. It is of four types :

1. **Spiral** (Alternate/Acyclic) A node bears only one leaf. Successive leaves may occur on opposite sides to form two alternate rows **(distichous)** or 3 (tristichous) or more (orthostichous) vertical rows of leaves.

Schimper Brown (Fibonacci) *series of divergence.* The leaves in spiral (alternate) phyllotaxy are arranged in 2 vertical rows (1/2 phyllotaxy), three rows (1/3), five rows (2/5 phyllotaxy), 8 rows (3/8 phyllotaxy) 13 rows (5/13), 21 rows (8/21 phyllotaxy). These phyllotaxic series (1/2, 1/3, 2/5, 3/8, 5/13, 8/21, 13/34, 21/55 etc.) are as per schimper brown series in which each number of the series is the sum total of numerator and denominator of the two previous ones, *e.g.*, 2/5 is 1/2 + 1/3 ; 3/8 is

2/5 + 1/3 and so on. Spiral phyllotaxy multiplied by 360° give angular divergence. A phyllotaxy is written by taking the number of spirals (circles) as *numerator* N^r and the number of rows or number of leaves as *denominator* D^r *e.g.*, 1/2 phyllotaxy means (a) there are two vertical rows of leaves (distichous) or (b) in one circle of 360° there are 2 leaves at angular divergence of 1/2 × 360° = 180° or (c) 3rd leaf is placed above I^{st} leaf at angular divergence of 180°. This is *simplest* phyllotaxy found in grasses. In 2/5 *phyllotaxy*, there are 5 vertical rows (*Pentastichous*) and 2 circles have 5 leaves at angular divergence of 2/5 × 360 = 144°. **Minimum angular divergence is 120° found in 1/3 phyllotaxy**.

2. Opposite (Cyclic). Two leaves occur on each node. It may be (a) **Opposite and Superposed**. Opposite leaves of successive nodes lie one above the other forming only two rows, *e.g.*, *Syzygium*, (b) **Opposite and Decussate**. Opposite leaves of successive nodes lie at right angles, forming four rows, *e.g.*, *Calotropis, Guava*. **Quisqualis (Rangoon creaper) shows both types of opposite phyllotaxy.**

3. Whorled or Verticellate. More than two leaves occur at each node, *e.g.*, 3 in *Nerium*/ Oleander, 5 to 6 in *Alstonia*, 4–5 in *Hydrilla* etc. *Cyclic phyllotaxy includes opposite and whorled phyllotaxy both.*

4. Leaf mosaic. In shade loving plants (sciophytes) the leaves are arranged in close spiral and small younger leaves fit like a mosaic in interspaces amongst the larger older leaves to avoid overlapping. This helps to get maximum light *e.g.*, *Acalypha.*

Prefoliation

It is arrangement of immature/young leaves in bud. It is of 2 types : (1) Ptyxis (ii) Vernation.

Ptyxis. It is folding of individual lamina in bud condition. It is of various types viz– **circinate** (rolled from apex to base like spring of watch *e.g.*, fern leaves), **plicate** (folded lengthwise along its veins like Japanese fan, *e.g.*, Fan Palm), **conduplicate** (folded over midirib, *e.g.*, *Bauhinia, Guava)*, reclinate (upper half bent over lower half, *e.g.*, Loquat), **crumpled** (irregular folding, *e.g.*, Cabbage), **Involute** (margins rolled on upper surface, *e.g.*, *Colocassia*), **revolute** (margins rolled on lower surface, *e.g.*, Oleander) and **Convolute** (lamina is rolled up length wise from one margin to other like dosa *e.g.*, *Banana*.

Vernation or Aestivation. Arrangement of young/immature leaves in bud condition with respect to one another is known as **vernation** *e.g.*, **imbricate** (irregular overlapping), **contorted** (twisted, regular overlapping of margins), **induplicate** (margin bent inwardly), **equitant** (conduplicate in two series, one overlapping the other completely). In floral bud, floral leaves are arranged in valvate, twisted, imbricate or quincuncial type of aestivation.

Venation

It is the arrangement of veins and veinlets in the lamina.

1. Reticulate Venation. Veins and veinlets form reticulations or networks. Reticulate venation generally occurs in **dicots**. Some monocots like aroids (*e.g., Colocasia, Alocasia*), *Dioscorea/ Arisaema* and *Smilax* also possess reticulate venation in their leaves.

(i) Pinnate or Unicostate Reticulate Venation. A single midrib giving lateral veins on both sides like a feather with veinlets forming net work, *e.g.*, Shoe Flower, Peepal, Mango.

(ii) Palmate or Multicostate Reticulate Venation. There are several main veins which start from base and proceed either towards tip (**Convergent palmate** reticulate, *e.g.*, *Zizyphus*) or towards margins (**divergent palmate** reticulate, *e.g.*, *Luffa*, Castor). The main veins give rise to lateral veins which in turn form veinlets. Veinlets form reticulation.

2. Parallel Venation. Veinlets are not conspicuous. Veins run parallel without forming reticula-

tions. Parallel venation is found in **monocots.** Some dicots like *Calophyllum, Corymbium, Eryngium* have parallel venation.

(i) **Pinnate or Unicostate Parallel Venation**. A single main vein or midrib occurs in the lamina. It gives rise to lateral veins running parallely on both the sides, *e.g.*, Banana, *Canna*.

(ii) **Palmate or Multicostate Parallel Venation** Reticulations are absent. Main veins run parallel or roughly parallel. A number of main veins arise from base of leaf blade and proceed either towards the tip (**convergent** palmate parallel, *e.g.*, Grass, Wheat, Bamboo) or margins (divergent palmate parallel, *e.g.*, Fan Palm).

Types of Leaves and Incision

Simple Leaf

A leaf with undivided lamina is known as **simple leaf.** Lamina may be entire or bear **incisions** without dividing it into distinct parts or leaflets. Leaf incisions can be fid (upto half), **partite** (more than half but not reaching base or midrib) and-**sect** (reaching near base or midrib). Depending upon the type of leaf and degree of incision, the leaves are called pinnatifid/palmatifid ; pinnatipartite/ palmatipartite; or pinnatisect/palmatisect.

Compound Leaf *

It is that leaf in which the lamina is divided completely into distinct and separate segments called leaflets. The leaflets do not bear axillary buds. Stipules are absent though stiples may occur in some cases. All the leaflets develop in the same plane and leaflets **always show reticulate venation.** Compound leaves are of two types :

(A) **Pinnate Compound Leaf.** These leaves are developed from pinnate venated simple leaf by pinnatisect incision. Leaflets are borne laterally on an elongated axis called rachis. Pinnate compound leaf is of the following types :

(1) **Unipinnate** (Simple Pinnate). Leaf is dvided only once in Pinnate manner. The leaflets are borne on rachis which is continuation of petiole. It may be; **Paripinnate unipinnate.** Leaflets are even in number and two leaflets occur at the tip of rachis, *e.g.*, *Tamarindus (Imli), Cassia*. **Imparipinnate unipinnate.** Leaflets are odd in number and there is one terminal leaflet, *e.g.*, *Murraya, Rose*.

(2) **Bipinnate**. It is a twice pinnate compound leaf. The leaflets are borne on branches of the rachis called rachillae or secondary axes. The leaflets are called pinnules, *e.g.*, *Acacia* (Kikar). *Mimosa* (Touch me not) *Albizzia* (siris). It is characteristic of *Mimosaceae*.

(3) **Tripinnate**. Leaf is thrice pinnate. Leaflets arise from the tertiary axis, *e.g.*, *Moringa* (Drum Stick/Sanjana), *Melia azedarach (Dharek)*.

(4) **Decompound**. Leaf is more than thrice pinnate, *e.g.*, *Parthenium*, Coriander, Carrot, Fennel. Development of leaflets is supressed and the ultimate branches become flattened and green.

(B) **Palmate Compound Leaf** The compound leaf gives the appearance of a palm. It has all the leaflets attached to the tip of petiole. These palmate compound leaves are developed from palmate, venated simple leaf by incision. **Rachis is absent**. Depending upon the number of leaflets a palmate compound leaf can be;

(1) **Unifoliate**. A single leaflet is borne at the tip of petiole, *e.g.*, *Citrus*. A **constriction** occurs between the two. In *Citrus*, the petiole is winged. The wing may expand to form two leaflets showing that unifoliate leaf of *Citrus* is derived from trifoliate one.

* Midrib becomes Rachis in Pinnate compound leaves. Rachilla is branch of rachis in Bi/tripinnate leaf. Rachis is absent in Palmate compound leaves. Leaflets are called Pinnules.

(2) **Bifoliate.** Two leaflets are found at the tip of petiole, *e.g.*, *Balanites, Hardwichia, Zorina.*

(3) **Trifoliate.** Three leaflets at tip, *e.g.*, *Oxalis, Aegle marmelos* (Bel).

(4) **Quadrifoliate.** Four leaflets at tip of petiole, *e.g.*, *Paris, Marsilea.*

(5) **Multifoliate (Multifoliolate) or Digitate** with more than four leaflets, *e.g.*, Cleome, Bombax.

Leaf Modifications

1. **Leaf Tendrils.** Leaf or leaf parts are modified into coiled thread like sensitive structures **called** tendrils. Leaf tendrils are *unbranched*, devoid of scale leaves and *bear axillary bud in axil.* They are of the following types :

(i) **Whole Leaf Tendrils.** The whole leaf is modified into tendril for climbing in Wild Pea (*Lathyrus aphaca*). The function of photosynthesis is carried by foliaceous stipules.

(ii) **Leaflet Tendrils.** Upper leaflets of Sweat Pea (*Lathyrus odoratus*) and Edible pea (*Pisum sativum*) are transformed into tendrils for climbing.

(iii) **Petiolar Tendrils.** Petioles function as tendrils in **Garden Nasturtium** (*Tropaeolum)* and *Nepenthes.*

(iv) **Rachis Tendrils.** *Rachis* and *petiolules* can function as tendrils in *Clematis* (old man beard).

(v) **Rachis Tip Tendrils.** The tip of rachis is modified into tendril in Lentil (*Lens culinaris*).

(vi) **Leaf Tip Tendrils.** In Glory Lily (*Gloriosa superba)* the leaf apices are sensitive to function as tendrils.

(vii) **Stipular Tendrils.** In *Smilax*, the tips of adnate stipules produce thick cord like tendrils.

2. **Leaf Spines.** Leaf spines occur in *Opuntia, Asparagus* and Barberry. Spines are branched in Barberry (3–5 rayed). Leaf spines of *Opuntia* are present in the region of areoles while they occur in place of scale leaves in climbing species of *Asparagus*. Stipular spines are found in *Acacia* and *Zizyphus*. Spines present at tips *(e.g., Agave*, Date Palm), margins (*e.g., Argemone*, Brinjal, Aloe) and suface (*e.g., Solanum surattense*) are actually prickles.

3. **Leaflet Hooks.** Three terminal leaflets of *Bignonia unguis-cati (Cat's claw)* are modified into curved hooks for climbing. In *Artabotrys*, the pedicel of flower is hooked.

4. **Leaf Roots.** In *Salvinia* (a water fern) one leaf of each node is tranformed into roots for balancing during floatation on water.

5. **Phyllodes (Phythode).** Phyllodes are flattened **petioles** and **raches** (singular–rachis) which have taken over the function of lamina as the latter is reduced. In several species of Australian Acacia (*e.g., A. melanoxylon, A. auriculiformis*), the *petiole and part of rachis* (Primary rachis) expands to form phyllode. Phyllodes are vertical, have fewer stomata and therefore, lose less water in transpiration. In *A. melanoxylon* the normal bipinnate leaves are also found alongwith phyllodes. In other species the seedling shows all the stages between bipinnate compound leaf and phyllode. In *Parkinsonia aculeata*, the rachis branches (*i.e.*, secondary rachi) are modified into phyllodes. Small leaflets also occur but they fall off very early. Phyllodes of Parkinsonia are **smallest. Phyllode is thus flat green foliaceaous petiole.**

6. **Leaf Modification in Insectivorous plants.** *Insectivorous* (carnivorous plants) grow in water logged/swarmy soils/ bogs deficient in nitrogen. Some are aquatic (*e.g., Utricularia, Aldrovanda*). To fulfil the deficiency of nitrogen, they trap insects **no bigger than butterflies** or grasshoppers or cockroaches and digest their proteins by extracellular digestion by enzymes like proteases/ pepsin. These plants depend only partially on this irregular nutrition as they have their own green leaves to synthesize food. They are actually *partly autotrophic, partly heterotrophic, primary producers* and

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Types of Leaves and Incision

Simple Leaf

A leaf with undivided lamina is known as **simple leaf**. Lamina may be entire or bear **incisions** without dividing it into distinct parts or leaflets. Leaf incisions can be fid (upto half), **partite** (more than half but not reaching base or midrib) and-**sect** (reaching near base or midrib). Depending upon the type of leaf and degree of incision, the leaves are called pinnatifid/palmatifid ; pinnatipartite/ palmatipartite; or pinnatisect/palmatisect.

Compound Leaf *

It is that leaf in which the lamina is divided completely into distinct and separate segments called leaflets. The leaflets do not bear axillary buds. Stipules are absent though stiples may occur in some cases. All the leaflets develop in the same plane and leaflets **always show reticulate venation.** Compound leaves are of two types :

(A) Pinnate Compound Leaf. These leaves are developed from pinnate venated simple leaf by pinnatisect incision. Leaflets are borne laterally on an elongated axis called rachis. Pinnate compound leaf is of the following types :

(1) **Unipinnate** (Simple Pinnate). Leaf is dvided only once in Pinnate manner. The leaflets are borne on rachis which is continuation of petiole. It may be; **Paripinnate unipinnate.** Leaflets are even in number and two leaflets occur at the tip of rachis, *e.g.*, *Tamarindus (Imli), Cassia*. **Imparipinnate unipinnate**. Leaflets are odd in number and there is one terminal leaflet, *e.g.*, *Murraya, Rose.*

(2) **Bipinnate**. It is a twice pinnate compound leaf. The leaflets are borne on branches of the rachis called rachillae or secondary axes. The leaflets are called pinnules, *e.g.*, *Acacia* (Kikar). *Mimosa* (Touch me not) *Albizzia* (siris). It is characteristic of *Mimosaceae.*

(3) **Tripinnate**. Leaf is thrice pinnate. Leaflets arise from the tertiary axis, *e.g.*, *Moringa* (Drum Stick/Sanjana), *Melia azedarach (Dharek).*

(4) **Decompound**. Leaf is more than thrice pinnate, *e.g.*, *Parthenium*, Coriander, Carrot, Fennel. Development of leaflets is supressed and the ultimate branches become flattened and green.

(B) Palmate Compound Leaf. The compound leaf gives the appearance of a palm. It has all the leaflets attached to the tip of petiole. These palmate compound leaves are developed from palmate, venated simple leaf by incision. **Rachis is absent**. Depending upon the number of leaflets a palmate compound leaf can be;

(1) **Unifoliate**. A single leaflet is borne at the tip of petiole, *e.g.*, *Citrus*. A **constriction** occurs between the two. In *Citrus*, the petiole is winged. The wing may expand to form two leaflets showing that unifoliate leaf of *Citrus* is derived from trifoliate one.

* Midrib becomes Rachis in Pinnate compound leaves. Rachilla is branch of rachis in Bi/tripinnate leaf. Rachis is absent in Palmate compound leaves. Leaflets are called Pinnules.

(2) **Bifoliate.** Two leaflets are found at the tip of petiole, *e.g.*, *Balanites, Hardwickia, Zornia.*

(3) **Trifoliate.** Three leaflets at tip, *e.g.*, *Oxalis, Aegle marmelos* (Bel).

(4) **Quadrifoliate.** Four leaflets at tip of petiole, *e.g.*, *Paris, Marsilea.*

(5) **Multifoliate (Multifoliolate) or Digitate** with more than four leaflets, *e.g.*, *Cleome*, Bombax.

Leaf Modifications

1. **Leaf Tendrils.** Leaf or leaf parts are modified into coiled thread like sensitive structures **called** tendrils. Leaf tendrils are *unbranched*, devoid of scale leaves and *bear axillary bud in axil.* They are of the following types :

(i) **Whole Leaf Tendrils.** The whole leaf is modified into tendril for climbing in Wild Pea (*Lathyrus aphaca*). The function of photosynthesis is carried by foliaceous stipules.

(ii) **Leaflet Tendrils.** Upper leaflets of Sweat Pea (*Lathyrus odoratus*) and Edible pea (*Pisum sativum*) are transformed into tendrils for climbing.

(iii) **Petiolar Tendrils.** Petioles function as tendrils in **Garden Nasturtium** (*Tropaeolum*) and *Nepenthes.*

(iv) **Rachis Tendrils.** *Rachis* and *petiolules* can function as tendrils in *Clematis* (old man beard).

(v) **Rachis Tip Tendrils.** The tip of rachis is modified into tendril in Lentil (*Lens culinaris*)

(vi) **Leaf Tip Tendrils.** In Glory Lily (*Gloriosa superba)* the leaf apices are sensitive to function as tendrils.

(vii) **Stipular Tendrils.** In *Smilax*, the tips of adnate stipules produce thick cord like tendrils.

2 **Leaf Spines.** Leaf spines occur in *Opuntia, Asparagus* and Barberry. Spines are branched in Barberry (3–5 rayed). Leaf spines of *Opuntia* are present in the region of areoles while they occur in place of scale leaves in climbing species of *Asparagus.* Stipular spines are found in *Acacia* and *Zizyphus.* Spines present at tips *(e.g., Agave*, Date Palm), margins (*e.g.*, *Argemone*, Brinjal, Aloe) and suface (*e.g., Solanum surattense*) are actually prickles.

3. **Leaflet Hooks.** Three terminal leaflets of *Bignonia unguis-cati (Cat's claw)* are modified into curved hooks for climbing. In *Artabotrys*, the pedicel of flower is hooked.

4. **Leaf Roots.** In *Salvinia* (a water fern) one leaf of each node is tranformed into roots for balancing during floatation on water.

5. **Phyllodes (Phythode).** Phyllodes are flattened **petioles** and **raches** (singular–rachis) which have taken over the function of lamina as the latter is reduced. In several species of Australian Acacia (*e.g., A. melanoxylon, A. auriculiformis*), the *petiole and part of rachis* (Primary rachis) expands to form phyllode. Phyllodes are vertical, have fewer stomata and therefore, lose less water in transpiration. In *A. melanoxylon* the normal bipinnate leaves are also found alongwith phyllodes. In other species the seedling shows all the stages between bipinnate compound leaf and phyllode. In *Parkinsonia aculeata*, the rachis branches (*i.e.*, secondary rachi) are modified into phyllodes. Small leaflets also occur but they fall off very early. Phyllodes of Parkinsonia are **smallest. Phyllode is thus flat green foliaceaous petiole.**

6. **Leaf Modification in Insectivorous plants.** *Insectivorous* (carnivorous plants) grow in water logged/swarmy soils/ bogs deficient in nitrogen. Some are aquatic (*e.g., Utricularia, Aldrovanda*). To fulfil the deficiency of nitrogen, they trap insects **no bigger than butterflies** or grasshoppers or cockroaches and digest their proteins by extracellular digestion by enzymes like proteases/ pepsin. These plants depend only partially on this irregular nutrition as they have their own green leaves to synthesize food. They are actually *partly autotrophic, partly heterotrophic, primary producers* and

secondary consumers (carnivores of first rank eating the insects feeding on plant). **Drosera** (sun-dew)– grow in peats/bogs/water logged areas (In India in rice fields in Eastern India Khasia hills and western Himalayas). It is a small herbaceous plant in which each leaf bears about 200 clubshaped glandular hairs (tentacles) with swollen glandular heads of reddish colour. They secrete a thick sticky purple juice *which shines in the sun like dewdrops* and attracts insects. Any insect happen to touch the head of a tentacle is stuck up by its sticky juice. The tentacles bend and get covered over by other tentacles and secrete digestive juice rich in *proteases* and Hcl to digest insect proteins (extra-cellular digestion). Then tentacles straighten. **Nepenthes** (pitcher plant), is an epiphytic/climber of South Asia and Garo Hills of north eastern India/Assam and Ceylon. The *lamina is modified into broad pinkish pitcher* of 1 to 10 inches in length; *leaf apex forms coloured lid to attract insect. Petiole becomes tendrillar* and leaf base becomes foliaceous (leaf like). At the rim of the pitcher are present nectariferous glands. The interior of pitcher is very slippery. The lower half of the pitcher bears digestive glands to fill the bottom of the pitcher. The insects like Grass hopper Cockroaches, ants when enter the pitcher in search of nectar, slip and get digested.

Sarracenia. It is also called Devil's boot, found in North American bogs; pitcher *is sessile.* 18 inches long (largest pitcher) tendrillar petiole absent.

Other pitcher plants: *Darlingtonia, Cephalotus, Heliamphora.*

Is *Dischidia* the whole leaf is changed into a pitcher (nest) to store rain water and humus rich soil. There is no lid. The nest roots (adventitious roots) absorb this water. This pitcher *is not insectivorous.*

***Utricularia* (Bladderwort).** It is an aquatic free floating, **rootless** insectivorous plant with dissected leaves. Some of the leaves are modified to form small *bladders* (utricles) each of 1–3 mm diameter. It grows in that season when insects (Cyclops and Daphnia) multiply more rapidly and thus it controls insect population. Each bladder has sensitive hairs branched trigger bristles sensitive to insect to open trap valve, a trap valve (Door valve); 2 celled external glands (to secrete mucilage and sugar to attract insects) and 4 celled internal glands (secrete acidic digestive juice rich in proteases and HCl). Trap valve is like a mouse trap and open inwardly.

***Dionaea* (Venus fly trap).** The bilobed lamina is modified into toothed jaws hinged to the midrib and open at an angle of 40 to 50°. Each jaw has 12–20 interlocking spiny teeth towards margin and 3 sensitive spines on upper surface and many reddish digestive glands. If an insect happens to touch a sensitive spine, the two lobes (jaws) of the lamina fold rapidly and trap the insect. This plant is inhabitant of North American bogs.

***Aldrovanda* (Water flea trap).** It is a **rootless** aquatic free floating insectivorous plant found in salt marshes of south Calcutta and is similar to *Dionaea* in having bilobed lamina with sensitive hairs, digestive glands, marginel teeth and bristles. Butterwort (*Pinguicula)* is a small herb. The upper surface of leaves bears mucilage and digestive glands. If a small animal crawls to the upper surface of the leaf, it is held up in the sticky mucilage and the margins of the leaf curl inwardly to trap the animal. It is found in European bogs and Alpine Himalayas (11000 to 13000 feet height).

INFLORESCENCE

Inflorescence is defined in different ways.

(i) Inflorescence (L. *inflorescence* = to begin to blossom) is the mode of arrangement and distribution of flowers on a specialised branch called peduncle (inflorescence axis, mother axis). [A flattened peduncle is called **receptacle**.] (ii) It is a system of branches bearing flowers. (iii) It is a branch or axis bearing flowers in definite manner. *Importance of inflorescence.* (a) It makes flower more conspicuous to pollinating agents (insects/birds) so that *chances of cross pollination* are high, (b) a

single pollinating agent can pollinate a number of flowers in a single visit, (c) Inflorescence usually occurs away from vegetative parts and thus avoid hinderances for the pollinating agencies (d) a large number of pollens are shed from a group of flowers in the inflorescence so that air pollination becomes easier (e) As *more flowers are pollinated at a time, more fruits are produced.*

Types. According to position, inflorescence can be terminal (*e.g.*, Poppy), intercalary (*e.g.*, bottle brush) and axillary (*e.g.*, Shoe flower).

Basically inflorescence are of following types :—

(A) Solitary Flowers

They are those flowers which are not grouped into inflorescence but occur singly in two ways.

1. **Solitary Terminal.** Single terminal flowers develop at the tip of main stem or its branches *e.g.*, Poppy (*Papaver*).

2. **Solitary Axillary.** Flower occurs singly in the axil of a leaf (*e.g.*, *Petunia*, China Rose/Shoe Flower = *Hibiscus rosa-sinensis*).

(B) Simple inflorescence

Peduncle is unbranched. It is of two types :—

(a) **Racemose Inflorescence.** In Racemose (indeterminate or indefinite) inflorescence, the peduncle grows continuously by apical bud and produces an unlimited number of flowers **acropetally** (young and smaller towards the growing point, older and larger towards the base). In case the peduncle remains small flattened the flowers come to have **centripetal arrangement** (younger towards the centre, older towards the periphery). Racemose inflorescence is called **simple** if the peduncle is unbranched and **compound** if the peduncle is branched. It is of following two types :—

(i) **Simple Racemose Inflorescence.** Peduncle is unbranched. The flowers open in centripetal manner, *i.e.*, inner (apical) flowers open last and outer (basal) flowers open first.

1. **Typical Raceme** (= Raceme) peduncle elongated unbranched, monopodial bearing pedicellate flowers in acropetal manner, *e.g.*, *Delphinium* (Larkspur), *Raphanus* (Radish), *Lupinus*.

2. **Spike** flowers are sessile and borne acropetally on elongated peduncle, *e.g.*, *Callistemon* (Bottle Brush), *Amaranthus, Achyranthes*. This is most common type of inflorescence.

3. **Spikelet.** It is a compact spike having a few (1 – 5) flowers borne on axis called **rachilla** and surrounded by two scales (= bracts) called **glumes**, *e.g.*, Wheat, Oat, Grass.

4. **Catkin** (Amentum). Compact pendent unisexual spike in which peduncle is thin and weak, *e.g.*, *Morous* (Mulberry), *Salix* (Willow), *Populus* (Poplar), *Betula* (Birch), *Acalypha* (Red hot cat tail). This inflorescance is found in group of families called Amentiferae.

5. **Spadix.** It is a modification of catkin/spike in which the peduncle is thick and fleshy with upper part sterile (called appendix) and lower part bearing male, neuter and female unisexual flower surrounded by a large bract called **spathe**, *e.g.*, Aroids (*Colocasia*), *Arum, Arisaema* (Cobra = Snake Plant). In Maize, *the female flowers develop in a spadix.* Spadix is found in monocot plants only.

6. **Corymb.** All the acropetally arranged pedicellated flowers come to lie at the same level due to slight shortening of peduncle in upper regin and slight elongation of pedicels of lower flowers *i.e.*, pedicels of flowers are of unequal length, *e.g.*, *Iberis amara* (Candytuft), *Caesalpinia*.

7. **Corymbose-raceme.** It is like a corymb near the growing point and raceme lower down, *e.g.*, *Brassica campestris* (Mustard).

8. **Umbel.** All pedicellate flowers arise centripetally around an *extremely reduced peduncle*

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7. **Corymbose-raceme.** It is like a corymb near the growing point and raceme lower down, *e.g.*, *Brassica campestris* (Mustard).

8. **Umbel.** All pedicellate flowers arise centripetally around an *extremely reduced peduncle*

(Peduncle is reduced to a point) like the ribs of an umbrella; an involucre (whorl of bracts) present at the base of flowers. Pedicels of all flowers are of equal length, *e.g.*, *Centella (= Hydrocotyle) asiatica* (Brahmi Booti).

9. **Strobile.** It is a spike having persistent and membranous bracts, *Humulus* (Hop).

10. **Capitulum (Racemose Head, Anthodium).** It is a characteristic of Compositae (Asteraceae). Peduncle is flattened called **receptacle** that bears centripetally arranged small sessile flowers called **florets** surrounded by involucre of bracts, *e.g.*, *Zinnia, Marigold, Helianthus, (Tagetes), Chrysanthemum, Sonchus, Ageratum.* Florets may be tubular, ⊕ (= disc florets) or ligulate, ⊖ (= ray florets). Capitula may be **homogamous** (all florets of one type), *e.g.*, only ligulate in *Sonchus* and only tubular in *Ageratum* or **heterogamous** (with two types of florets, *e.g.*, Sunflower (*Helianthus annuus*) is heterogamous with both **ray florets** (towards periphery) and **disc florets** (towards centre).

11. **Capitate or Special Head.** A number of sessile flowers grow on a suppressed peduncle in centrifugal manner forming a globose inflorescence, *e.g.*, *Acacia, Albizia, Mimosa.*

(ii) **Compound Racemose Inflorescence.** The peduncle is branched and each branch bearing flowers in any of the racemose manner.

1. **Raceme of racemes (Compound Raceme or Panicle).** Peduncle is branched in acropetal (raceme) manner and racemes are borne acropetally on each branch of peduncle, *e.g.*, *Cassia fistula, Delonix regia, Yucca, Asparagus, Asphodelus*, male flower of Maize (tassel).

2. **Corymb of corymbs (Compound Corymb).** An axis bearing a number of corymbs in a corymbose fashion, *e.g.*, *Pyrus*, Cauliflower. Edible Cauliflower (*Brassica oleracea* var. *botrytis*) represents an undeveloped inflorescence.

3. **Umbel of umbels (= Compound Umbel).** Peduncle is branched in umbel manner into rays. Each ray bears pedicellated flowers in umbel manner (secondary umbel or umbellule). It is characteristic of family **Umbelliferae** (Apiaceae). Involucre (below mother umbel) and involucels (below each daughter umbel called umbellule) may be present, *e.g.*, Coriander, Fennel, Carrot, Cumin.

4. **Spike of spikes** (compound spike) *e.g.*, *Amaranthus spinosus* (chaulai).

5. **Spike of spikelets.** *e.g.* Wheat, Sorghum. In Gramineae (Poaceae, grass family) peduncle is branched. Each branch called rachilla bears a group of 1–5 sessile florets called **spikelet.** Thus unit of inflorescence is not a single flower but a group of 1–5 flowers. All spikelets are covered by two empty bracts/scales called *glumes*. Spikelets are sessile in wheat and pedicellated in Rice. A floret has lemma (bract), palea (bracteole), 2 lodicules (tepal), 3 to 6 stamens and one ovary.

6. **Panicle of spikelets**, *e.g.*, Rice. Spikelets are pedicellated.

7. **Spike of spadices** (Compound Spadix), *e.g.*, Date Palm, Coconut, Female flower in Maize, Banana.

8. **Capitulum of capitula.** (Compound capitulum), *e.g.*, *Echinops.*

(b) **Cymose Inflorescence.** It is also called definite or determinate inflorescence because the growing point of the peduncle is used up in the formation of a flower. Further growth of the flowering axis is continued by one or more lateral braches which also end in flowers. Flowers are terminal, floral axis (peduncle) is sympodial, number of flowers are limited and flowers are arranged in basipetal (centrifugal) manner *i.e.*, apical (upper) flowers are older than the basal (lower) flowers and flowers open centrifugally, *i.e.*, inner flowers open first followed by outer (basal) flowers. It is of following types.

1. **Uniparous or Monochasial Cyme.** The flowering axis is **sympodial**. As the growing point ends in a flower, further growth is continued by a lateral branch which also ends in a flower. The process is repeated. It is of two types :—

(i) **Helicoid uniparous.** All the flowers are borne on the same side, *e.g., Begonia, Drosera.* It can be **dreponium** (flowers in one plane) or **bostryx** (flowers in different planes).

(ii) **Scorpioid uniparous.** The flowers are borne on both sides alternately on zig zag peduncle, *e.g., Tecoma, Freesia, Heliotropium.* **Rhipidium** is scorpioid cyme having all the flowers in one plane (*e.g., Solanum nigrum)* while in **cincinnus** the flowers are borne in different planes.

2. **Biparous or Dichasial Cyme or Dichasium.** Growth of the flowering axis is continued by two branches when the growing point of the parent axis is converted into a flower, *e.g., Dianthus* (Pink), *Silene, Nyctanthes, Jasminum, Clerodendron, Bongainvillea*, Teak. Arrangement of flowers is either **basipetal** (when axis is elongated) or **centrifugal** (if axis is short).

3. **Multiparous or Polychasial Cyme or Polychasium.** More than two branches continue growth of the flowering axis when the parent axis is changed into a flower, *e.g., Calotropis, Hamelia, Asclepias.* Arrangement of flowers is generally centrifugal.

4. **Cymose Head** (Glomerule). A number of centrifugally arranged sessile or subsessile flowers are borne around a globular receptacle without involucre of bracts, *e.g., Anthocephalus cadamba* (Kadam).

5. **Scapigerous Cyme Umbel.** In onion (*Allium cepa*) a scape (a leafless peduncle/shoot arising from terminal bud) from ground level bears an umbellate cyme covered (by one or more spathes).

(C) Mixed Inflorescence

These inflorescences have both the characters of racemose and cymoses.

1. **Thyrsus** (Thyrse). Many cymose clusters are arranged acropetally on axis with unlimited growth, *e.g., Vitis vinifera* (Grape Vine and male *Cannabis*).

2. **Mixed Spadix** (Spadix of Cymes). Spadices having cymose inflorescence arranged acropetally on fleshy axis, *e.g.,* Banana.

3. **Panicle of Spikelets.** Spikelets are pedicellated arranged in a compound raceme, *e.g.,* Oat, Rice.

4. **Corymb of Capitula**, *e.g., Ageratum.*

5. **Other Types** — like umbel of capitula, cyme of capitula (*e.g., Vermonia*), cyme of umbels (*e.g., Lantana)*, cyme of corymbs, etc.

(D) Special Inflorescences

These are modified simple cymose inflorescences formed due to over crowding of flowers.

1. **Hypanthodium.** It is a modified spike and cyme inflorescence adapted for myrmecophily (pollination by ants). It is a fruit like *inflorescence.* It has a flask or cup shaped fleshy receptacle, a pore (ostiole) lined by scales and a short canal bearing hair. Internally the receptacle bears male flowers towards ostiole, female flowers towards base and sterile (neuter) female flowers (called gall flowers) between the two, *e.g., Ficus* (Peepal, Banyan, Fig). Gall flowers contain pupa/egg of pollinating insect. These flowers are arranged in cymose groups. The receptacle of this inflorescence is formed by the **condensation of rachis of three closely placed cymes.** It is **cauliflorous** (cladanthous) and develops from dormant bud on old stem.

2. **Coenanthium.** It has an open saucer-shaped receptacle bearing florets as in hypanthodium, *e.g., Dorstenia.*

3. **Verticillaster.** It is a raceme of verticels (whorls of flowers) borne on rectangular axis in the axils of opposite leaves. At each node there are two vertices. Each whorl consists of two clusters of 3–9 flowers with each cluster formed of a condensed dichasial cyme ending into monochasial scorpiod cyme, *e.g.*, *Ocimum*, *Salvia*, *Leucas*, Mint (*Mentha*), Lavender, Coleus (all belonging to family Lamiaceae (Labiatae).

4. **Cyathium.** It is a modified cyme that looks like a flower and is a characteristic of *Euphorbias*. It consists of cup like involucre formed by fusion of 5 bracts that encloses a single central achlamydeous (naked) pedicellate female flower surrounded by 5 groups of male flowers. In each group, male flowers are arranged centrifugally in uniparous scorpioid manner, *e.g.*, *Euphorbia*, *Poinsettia* and *Pedilanthus* (Jew's slipper). In *Poinsettia*, bracts become red. Thus **ratio of female : male flowers is 1 : many or more precisely 1 : 5**. Each male flower is bracteate, pedicellated and naked without sepal, petal and carpel and is represented by a single pedicellated stamen. There is a joint between stamen and pedicel which represents **thalamus**. The female flower is pedicellated and represented by single tricarpellary syncarpous pistil. Female flower matures earlier than the male flower (protogyny).

FLOWER

Flower is a highly modified and condensed shoot meant for sexual reproduction. It is characteristic of angiosperms. The axis on which the flower develops is called peduncle or mother axis. This represents the posterior side. The function of flower is to produce pollen grains and eggs, to provide attraction for pollinating agents; sometime helps in dispersal of fruits (*e.g.*, Pappus in Parachute mechanism) and provide nectar to insects for making honey. Following points can be mentioned to justify that **flower is a modified shoot** :—

The broadened base of flower that lies at the tip of pedicel is called **torus*** or **thalamus** or **receptacle**. The thalamus is a highly condensed shoot where internodes are too small. It represents **three condensed internodes and four nodes.** In certain cases it gets elongated. The elongated internode of thalamus between calyx and corolla is called **anthophore** (*e.g.*, *Silene*, *Dianthus*), **androphore** or **gonophore** between petals and stamens (*e.g.*, *Pasiflora*). **gynophore** between stamens and pistil (*e.g.*, *Cleome*, *Capparis*, Pea, *Euphorbia*, *Pterospermum*) and **gynandrophore/androgynophore** when both andro and gynophores are present in the same flower *e.g.*, *Cleome* (= *Gynandropsis*). **Carpophore** is the prolongation of the thalamus in between the two fused carpels *e.g.*, Coriander, fennel, cumin.

Torus or thalamus bears four types of **floral organs** arranged in cyclic manner in 4 whorls on nodes as outermost sepals (calyx), petals (corolla), stamens (androecium) and inner most carpels (gynaecium). Sepals and petals are called **nonessential** or **accessory floral organs** because they do not take part in sexual reproduction. Stamens and carpels are **essential/reproductive floral organs** because they take part in sexual reproduction.

In rose, pear, thalamus grows above the pistil and bears leafy shoot above flower. It is called monstrous type of development. In *Mussaenda*, one sepal is enlarged to form a attractive leafy structure with reticulate venation (called **advertisement flag)** and helps to attract pollinating agents. It confirms that sepals are modified leaves. In some cases floral buds are transformed into vegetative buds/bulbils *e.g.*, *Agave*. The stamens and carpels in primitive flowers like *Degenaria* are like a leaf. **Transition** from sepals to stamens through petals is seen in *Nymphaea* and Rose. This phenomenon is called *phyllody or chloranthy*. In *Canna*, stamens become green leaf like (petalloid staminode). In

* Term torus is related to thalamus, spongy thalamus of lotus and a suberised swelling in membrane of bordered pit.

Antigonon, floral buds are modified into tendrils. The structure of anther and carpel is similar to leaf. Sepals are leaf like in Rose. In *Paeonia*, there is gradual transformation of foliage leaves into bract, sepal and petal. In *Canna*, stamens are petaloid. In *Dagenaria* stamens and carpels are leaf like folded structures.

Terms for the Description of Flower

Flower :

1. (a) **Bracteate**	A flower borne in the axil of a bract (a leaf like structure at the base of pedicel).
(b) **Ebracteate**	A flower lacking a bract.
2. (a) **Bracteolate**	Bracteoles present on a pedicel, *e.g.*, *Delphinium*.
(b) **Ebracteolate**	Bracteoles absent on a pedicel.
3. (a) **Pedicellate**	A flower borne on a pedical (stalk).
(b) **Sub-sessile**	Flower borne on an inconspicuous pedicel, *e.g.*, *Albizzia*.
(c) **Sessile**	A flower lacking a pedicel, *e.g.*, *Helianthus*.
4. (a) **Complete**	A flower bearing all the four floral whorls.
(b) **Incomplete**	A flower lacking one or more kinds of floral whorls *e.g.*, *Ricinus*, *Euphorbia*.
5. (a) **Hermaphrodite or perfect/bisexual/ intersexual/ androgynous/ monoclinous**	A flower having both the essential organs *i.e.*, stamens and pistils.
(b) **Imperfect or unisexual or diclinous**	A flower containing either stamens or pistils, *e.g.*, *Lufta*, *Zea*. These are of two types namely **staminate** (androecious) which bear the stamens and pistil absence, *e.g.*, *Euphorbia*, Maize, Papaya, Coconut, *Vallisneria* and **pistillate** (gynaecious) bearing pistil/ pistils but stamens absent.
(c) **Neuter**	A flower when both stamens and pistils are absent or nonfunctional, *e.g.*, ray florests of *Helianthus annuus*.
6. (a) **Monoecious**	A plant bearing flowers of both sexes, *i.e.*, staminate and pistillate flowers, *e.g.*, *Ricinus* (castor-bean), *Zea* (maize) and cucurbits.
(b) **Dioecious**	When staminate and pistillate. Flowers are borne on separate plants. Examples: *Morus* (mulberry), *Carica papaya* (Papaya) and *Cannabis* (Bhang).
(c) **Trioecious**	A plant bearing three types— male, female and bisexual separately, *e.g.*, *Silene*.
7. (a) **Polygamous**	A single plant bearing staminate, bisexual (intersexual) and neuter flowers but males are more *e.g.*, *Mangifera* (mango), *Anacardium* (cashew-nut).
(b) **Androdioecious**	Some plants are staminate and others of same species are bisexual.
(c) **Gynodioecious**	When some plants are female and others of same species are bisexual.
(d) **Gynomonoecious**	A plant with bisexual and female flowers on same plant, *e.g.*, sunflower.
(e) **Andromonoecious**	A plant with bisexual and male flowers on same plant, *e.g.*, some lilies.
8. (a) **Achlamydeous**	A flower without perianth (sepals and petals) *e.g.*, *Euphorbia*.
(b) **Monochlamydeous**	A flower with only one whorl of perianth (nonessential floral organ), *e.g.*,*Ricinus*.
(c) **Dichlamydeous**	A flower with both the nonessential floral whorls of perianth, *i.e.*, calyx and corolla, *e.g.*, *Brassica*.
(d) **Homochlamydeous**	When the two whorls possess same colour *e.g.*, Lily.
(e) **Heterochlamydeous**	When the two whorls possess different colours *e.g.*, *Petunia*.
9. **Isomery**	It is presence of same basic number in different floral organs of a flower. An isomerous flower can be trimerous, bimerous, tetramerous, pentamerous.
(a) **Trimerous**	The floral parts are in multiples of three, *e.g.*, *Asparagus*.

(b) **Tetramerous**	The floral parts in multiples of four.
(c) **Pentamerous**	The floral parts in multiples of five.
(d) **Heteromerous (Anisomerous)**	In a flower, different floral organs have different basic number, *e.g.*, P_3, A_6, G_2
10. **Floral Phyllotaxy**	It is arrangement of floral leaves in floral bud. It is of three types :
(a) **Cyclic**	When floral organs are borne in whorls.
(b) **Cyclic or Spiral Phyllotaxy**	Floral organs in a floral bud are arranged in spiral manner.
(c) **Spirocyclic (hemicyclic)**	The essential organs are borne in spirals while the non essential floral organs occur in whorls, *e.g.*, *Ranunculus* (buttercup).
11. **Floral Symmetry**	
(a) **Actinomorphic.**	A flower that can be vertically divided in two equal halves by any vertical division passing through centre. Such flowers are also called **radially symmetrical**. *e.g.*, *Brassica*.
(b) **Zygomorphic**	A flower that can be divided vertically into two equal halves in one plane only. Such flowers (*e.g.*, *pea*) have **bilateral symmetry** (symmetry of one plane). It can be laterally zygomorphic ∅ or medianly zygomorphic ⦶.
(c) **Asymmetric**	It can not be divided into two equal halves by any plane, *e.g.*, *Canna*.
12 (a) **Regular**	Flowers with individuals of each whorl (*e.g.*, sepals/petals/stamens) having equal size and shape and spaced equally in position. Regular flowers are actinomorphic.
(b) **Irregular**	Sepals/petals/stamens are of variable size and shape and are also unequally spaced in position. Irregular flowers are zygomorphic, *e.g.*, *Pea*.
13. **Position of floral parts on thalamus :**	
(a) **Hypogynous**	When ovary is superior occupying highest position and other floral parts inferior arising from below the ovary.
(b) **Epigynous**	When ovary is inferior and other floral organs are superior.
(c) **Perigynous**	When ovary is semi superior.
(A) CALYX	It is the outermost whorl of the flower, represented by sepals. It provides protection to other floral organs as well as prevent rapid transpiration from inner parts of the flower. A sepal lying in line with mother axis is **odd sepal**, if the number of sepals is 3 or 5 odd sepal is mostly posterior but it is *anterior in Leguminosae*.
1. (a) **Polysepalous (Chorisepalous)**	Calyx of free sepals, *e.g.*, *Ranunculus*.
(b) **Gamosepalous (Synsepalous)**	Calyx of sepals fused (united) along their lateral margins *e.g.*, *Petunia*.
2. (a) **Sepaloid**	Sepals green.
(b) **Petaloid**	Sepals are brightly coloured other than green and look like the petals, *e.g.* *Delphinium*
3. (a) **Caducous**	Sepals fall off just before the flowers open perfectly, *e.g.*, *Papaver*.
(b) **Deciduous**	Sepals fall off at the time of withering of flower at maturity after fertilization, *e.g.* *Brassica*.
(c) **Persistent**	Sepals persist till the fruit formation and are present even in the mature fruit. It can be **accrescent** (sepals grow in size, remain green and may cover the fruit, *e.g.*, Brinjal, Chillies, Tomato, *Physalis*) or **marcescent** (sepals do not grow with the growth of fruit and become dry, *e.g.*, *Guava*, *Piper*.
4. (a) **Superior**	Calyx of epigynous flowers, *e.g.*, *Cucurbita*.
(b) **Inferior**	Calyx of hypogynous and perigynous flowers.

5. **Shape**
   (a) **Tubular** — Fused sepals form a tube like structure.
   (b) **Campanulate** — Fused sepals forming a bell-shaped strucuture, *e.g., Hibiscus.*
   (c) **Infundibuliform** — Fused sepals are funnel shaped, *e.g., Atropa.*
   (d) **Spurred** — Sepal modified into a beak-like sturcuture, called the **spur,** *e.g., Delphinium.*
   (e) **Balloon like** — *e.g., Physalis.*
   (f) **Bilabiate** — Fused sepals form two lipped structure, *e.g., Saliva*
   (g) **Reflexed** — The individual sepals are bent downwards and backwards, *e.g., Ranunculus.*
   (h) **Pappus** — Hair like persistant, helping in fruit dispersal, *e.g., Sonchus,* .
   (i) **Foliaceous** — Leafy, *e.g., Mussaenda.*
   (j) **Spinous** — *e.g., Trapa* (water chestnut) 2 sepals form spines on fruit.

6. **Aestivation** — It is the arrangement of sepals/petals in relation to one another in a floral bud. It is of 4 types.
   (a) **Valvate** — Sepals/ petals meet by their edges but do not overlap.
   (b) **Twisted (contorted)** — Margins of sepals/petals overlap regularly *i.e.,* one margin of a sepal overlap the next and the other margin is overlaped by preceding sepal.
   (c) **Imbricate** — Margins overlap irregularly. One petal/sepal is completely external. One is completely internal and remaining in twisted manner.
   (d) **Quincuncial** — Here two petals/sepals are external, two are internal and rest twisted.

(B) EPICALYX — It is an additional whorl of sepal like structure formed by **bracteoles.** It is present outer to calyx whorl and is found in Malvaceae (*Hibiscus, Althaea Gossypium* except in *Sida, Abutilon*). A flower with epicalyx whorl is called **pentacyclic.**

(C) COROLLA — It is second whorl of flower present inner to calyx and meant for attraction. It consists of petals.

1. (a) **Polypetalous** — Corolla of free petals, *e.g., Ranunculus.*
   (b) **Gamopetalous** — Corolla of petals fused (connate) along their lateral margins, *e.g., Petunia.*
2. (a) **Sepaloid** — Petals green like sepals, *e.g., Magnolia.*
   (b) **Petaloid** — Petals colored other than green.
3. (a) **Superior** — Corolla of epigynous flowers, *e.g., Helianthus* (sunflower).
   (b) **Inferior** — Corolla of hypogynous and perigynous flowers, *e.g., Lathyrus.*
4. **Shapes/forms**
   (a) **Cruciform** — Corolla of four, free, regular clawed or unguiculate petals arranged diagonally to form a cross. Each unguiculate or clawed petal consists of a proximal narrow stalk or claw and an expanded broad distal limb, *e.g., Brassica.*
   (b) **Caryophyllaceous** — Corolla of five, free, regular clawed petals with limbs at right angles to the claws, *e.g., Dianthus,* (*Pink*).
   (c) **Rosaceous** — Corolla of five or more free, regular, spreading petals with conspicuous limbs and inconspicous claws, arranged in a saucer-shaped manner, *e.g., Rosa* (rose).
   (d) **Papilionaceous** — Corolla butterfly shaped and consists of five, free irregular, petals arranged in descending imbricate aestivation. Odd posterior petal is called **standard** or **vaxillum** and is the largest and outermost. It overlaps a pair of smaller lateral petals called **wings** or **alae**. The alae in turn overlap a boat-shaped **keel** or **carina** formed by the connation of two small antero-lateral petals, *e.g., Lathyrus* (sweet pea), *Pisum* (edible pea). The keel encloses stamens and carpels.
   (e) **Infundibuliform** — The fused petals form a funnel-shaped structure, *e.g., Datura, Petunia.*
   (f) **Tubular** — Petals fused, forming a cylindrical tube-like structure, *e.g.,* Discfloret of sunflower, *Albizzia, Acacia.*

(g) **Bilabiate**	The fused petals form a tube that opens out into two distinct lips or lobes at the distal end. It is of two types, *i.e.*, **bilabiate ringent** (the two lips are open, *e.g.*, *Salvia, Ocimum*), **bilabiate personate** (the two lips are appressed or closed, *e.g.*, *Antirrhinum*).
(h) **Ligulate**	The fused petals form a strap-shaped structure towards the upper end. A small hairy outgrowth, the *ligule* is present at the junction of the strap and the tube, *e.g.*, ray florets of *Helianthus* (sunflower).
(i) **Apetalous**	Petals are absent in the flower, *e.g.*, *Clematis, Saraca.*
5. **Aestivation**	Same as to calyx.
Perianth	When sepals and petals are undifferentiated the term perianth is used. Its members are called tepals. Term polytepalous (polyphyllous) and gamotepalous (gamophyllous) are used for free or fused tepals. In grasses, perianth is scale like called **lodicule**.
(D) ANDROECIUM	It is the male reproductive organ and comprises stamens. Each stamen has 3 parts, a filament, connective and anther. In *Arum*, filament is absent. An anther can be bilobed (dithecous) or one lobed (monothecous). Each lobe has two chambers (Pollen sacs or microsporangia). Thus a dithecous stamen has four sacs and there are two sacs in a monothecous stamen. **Connective is absent in monothecous stamen**. Inside the pollen sacs, pollen grains are produced on *sporic meiosis.*
1. (a) **Polyandrous**	Stamens are many and free from one another, *e.g.*, *Ranunculus.*
(b) **Cohesion of anthers**	Union of stamens among themselves.
(i) **Synandrous**	The stamens are many and fused both by their filaments and anthers, *e.g.*, *Cucurbita.*
(ii) **Syngenesious** or **Synantherous**	Anthers fused, filaments free in a flower, *e.g.*, *Helianthus.*
(iii) **Monoadelphous**	Filaments of all the stamens fused to form a staminal tube that bears free anthers. *Hibisus rosa-sinensis* (Shoeflower) $A_{(\infty)}$.
(iv) **Diadelphous**	The filaments are united forming **two bundles**, *e.g.*, in *Lathyrus* (sweet pea), *Pisum* (edible pea) there are 10 stamens; filaments of 9 stamens are fused forming one bundle and the other bundle is represented by the filament of the tenth free stamen ($A_{1+(9)}$).
(v) **Polyadelphous**	The stamens are united by their filaments to form **many (three** or **more)** bundles, *e.g.*, *Citrus* (orange).
2. (a) **Isostamenous**	All the stamens of a flower are of equal lengths, *e.g.*, Buttercup, *Solanum.*
(b) **Heterostamenous**	Stamens in a flower are of unequal lengths, *e.g.*, *Cassia.*
3. (a) **Didynamous**	There are four free stamens in a flower, two have short filaments and two have long filaments, *e.g.*, *Ocimum.*
(b) **Tetradynamous**	There are six free stamens, inner four are large and outer two are small, *e.g.*, *Brassica* (mustard).
4. (a) **Alternipetalous**	Stamens alternating with the petals, *e.g.*, *Petunia.*
(b) **Antipetalous**	Stamens inserted opposite the petals, *e.g.*, *Primula* (primrose).
(c) **Antiphyllous**	Stamens inserted opposite the tepals, *e.g.*, *Asparagus.*
5. (a) **Diplostamenous**	Stamens inserted in two whorls ; outer whorl is alternipetalous, whereas inner whorl is antipetalous ; *e.g.*, *Murraya.*
(b) **Obdiplostamenous**	Stamens insterted in two whorls ; outer whorl is opposite to petals, *i.e.*, antipetalous whereas inner whorl is alternipetalous, *e.g.*, *Dianthus.*
(c) **Polystamenous**	Stamens in more than two whorls.

6. **Adhesion of stamens**	It is union of stamens with other floral organs of the flower.
(a) **Episepalous**	Stamens attached to the sepals, *e.g.*, *Prunus* (peach).
(b) **Epipetalous**	Stamens adnate with petals, *e.g.*, *Petunia*.
(c) **Epiphyllous or Epitepalous**	Stamens adnate with tepals, *e.g.*, *Asparagus*.
(d) **Gynandrous**	Stamens adnate with the pistil, *e.g.*, *Calotropis*. It is called **gynostegium** when stamens form a protective covering around stigma (style is tree), *e.g.*, *Calotropis*. It provides landing for pollinating agent or **gynostemium** when stamens are fused with style and sigma to form a column like structure, *e.g.*, *orchids*. It does not provide landing site for pollinator.
7. (a) **Exserted**	Stamens longer than the petals and come out, *e.g.*, *Acacia* (**Babul**).
(b) **Inserted**	Stamens remaining inside the corolla petals, *e.g.*, *Petunia*.
8. (a) **Monothecous**	Anther single-lobed, 2 chambered (bisporangiate), *connective is absent, e.g.*, *Malva*, *Althaea*, *Hibiscus*, etc.
(b) **Bithecous**	Anthers with two anther lobes and 4 chambers (testrasporangiate), *e.g.*,*Brassica*.
9. (a) **Staminode**	Under-developed, sterile stamens nonfunctional that do not produce pollens, *e.g.*, *Salvia*, *Cassia*, *Canna*.
(b) **Fertile stamen**	Stamens producing pollen grains
10. **Fixation of anthers**	
(a) **Adnate**	The filament is attached along the entire length of the anther from base to the apex, *e.g.*, *Ranunculus*, *Magnolia*, *Michelia*.
(b) **Basifixed or innate**	The tip of the fialment is attached to the base of the anther, *e.g.*, *Brassica*.
(c) **Dorsifixed**	The filament is attached to the back (abaxially) of the anther firmly at a point but the anther is not free to swing, *e.g.*, *Passiflora*.
(d) **Versatile**	The filament is attached to the back of the anther at a point in the middle and the anther can freely swing (sea saw movement) on the filament, *e.g.*, grass (wheat, maize). Versatile stamen is of two types :
(a) **Divaricate (Divergent) versatile**	Connective enlarges to separate both anther lobes but not completely, *e.g.*, Grasses, *Justicia*.
(b) **Distractile versatile**	connecting is long stalk like saparating both anther lobes completely, *e.g.*, *Salvia*, lilies, usually one anther lobe become sterile. It forms lever mechanism for entomophily.
11. **Dehiscence of Anthers**	It is splitting open of the anther lobes to shed the pollen grains (i) **Longitudinal slits** appear length wise ; it is further of three sub-types, *i.e.*, (a) **Laterorse**, when the slits appear along the sides between the two pollen sacs of an anther lobe, *e.g.*, *Datura*; (b) **Introrse**, when the slits appear on the inner side facing the pistil, *e.g.*, *Murraya* ; (c) **Extrorse**, when the slits appear towards the outer side of flower, *e.g.*, *Ranunculus* ; (ii) **Transverse** when the slits appear in transverse plane, *i.e.*, breadth wise *e.g.*, *Althaea*, (iii) **Porous**, when dehiscence by terminal pores, one at each another lobe tip, *e.g.*, *Solanum* ; (iv) **Valvular** in which flap-like valves appear on the anthers and the uplifting of the valves helps in the release of the pollen grains, *e.g.*, Barberry ; (v) **Irregular**, in which the walls of the anthers split open irregularly to shed the pollen grains, *e.g.*, *Najas*.
(E) GYNOECIUM (= Gynaecium)	It is the fourth and inner most whorl and represents, female reproductive organ of the flower. It consists of one or more than one pistil. Each pistil is made up of one (simple) pistil) or more than one carpels (compound pistil). Each carpel has 3 parts : **Pollen receiving** region called **stigma**; a stalk called **style**; and swollen ovules containing **ovary**.

1. **Number of Carpels**
   - (a) **Monocarpellary** — Gynoecium consisting of a single carpel, *e.g., Lathyrus.*
   - (b) **Bicarpellary** — Gynoecium consisting of two carples, *e.g., Petunia.*
   - (c) **Tricarpellary** — Gynoecium consisting of three carpels, *e.g., Asparagus.*
   - (d) **Tetracarpellary** — Gynoecium consisting of four carpels.
   - (d) **Pentacarpellary** — Gynoecium consisting of five carples, *e.g., Malva*
   - (e) **Poly(multi)carpellary** — Gynoecium consisting of many, *i.e.,* more than five carpels, *e.g., Althaea*
2. **Cohesion of carpels**
   - (a) **Apocarpous** — Gynoecium consisting of two to many free carples. Each carpel forms its own pistil, *e.g., Ranunculus* (butter-cup), Lotus, Rose.
   - (b) **Syncarpous** — Gynoecium consisting of two or more carpels **fused** laterally forming a compound pistil, *e.g., Petunia*, mustard.
3. **Position of ovary**
   - (a) **Superior ovary** — Gynoecium of hypogynous and perigynous flowers, *e.g., Petunia, Rosa.*
   - (b) **Inferior ovary** — Gynoecium of epigynous flowers, *e.g., Helianthus.*
4. (a) **Unilocular** — Ovary with a single chamber, *e.g., Dianthus, Lathyrus.*
   - (b) **Bilocular** — Ovary having two chambers or loculi as a result of the formation of septum (pl. septa), *e.g., Petunia.*
   - (c) **Trilocular** — Ovary having three chambers or loculi due to the formation of septa, *e.g., Asparagus.*
   - (d) **Pentalocular** — Ovary having five chambers or loculi, *e.g., Hibiscus.*
   - (e) **Polylocular or multilocular** — Ovary having many chambers, *e.g., Althaea* (Holyhock).
5. **Pistillode** — Pistil is underdeveloped, reduced and sterile, *e.g., Staminate flowers of Luffa, Cucurbita*, Gal flowers.
6. **Position of ovary** — Vertical, lateral, oblique (distorted).
7. **Position of style** — Terminal/lateral/gynobasic, In gynobasic style, style arises from middle of the ovary or direct from thalamus, *e.g., Salvia, Ocimum.*
8. **Placentation** — Axile, marginal, basal, free central, parietal, superficial.

SELECTED FAMILIES OF ANGIOSPERMS

Description of Flower

Following terms are used to describe the flower :

Inflorescence : Type— solitary, racemose, cymose, compound, special.

Flower : Bracteate/Ebracteate; bracteolate or ebracteolate; complete/Incomplete; perfect/hermaphrodite or imperfect/unisexual; pedicellate/sessile; actinomorphic or zygomorphic; hypogynous or epigynous or perigynous; pentamerous/trimerous/tetramerous; colour and shape.

Calyx : Number of sepals; polysepalous (free) or gamosepalous (fused); sepaloid (green) or petaloid (coloured); Aestivation (valvate, twisted, imbricate or quincuncial); deciduous or caducous or persistent; superior/inferior (If ovary is superior, all other floral parts become inferior or vice versa); shape.

Corolla : Number of petals, polypetalous or gamopetalous, sepaloid/petaloid, aestivation, colour, shape (tubular, ligulate, papilionaceous, cruciform, infundibuliform, rotate, rosaceous, bilabiate).

Perianth : When sepals and petals are indistinct, term tepal is used. Polyphyllous (free)/ gamophyllous (fused), description similar to sepals.

Androecium : Number of stamens, free (polyandrous), cohesion like adelphous (monoadelphous, diadelphous, polyadelphous), syngenesious (synantherous)/synandrous; Adhesion (adnation) like epipetalous/epiphyllous/gynandrous; dithecous or monothecous; extrorse or introrse; fixation of anther (adnate, basifixed, Dorsifixed, versatile), dehiscence; arrangement (antipetalous or alternipetalous); diplostamenous or obdiplostamenous; length of stamens (didynamous/tetradynamous/ heterostamenous).

Gynaecium (gynoecium) : Simple pistil (made up of one carpel) or compound pistil (made up of 2 or more carpels); number of carpels (mono/bi/tri/tetra/penta-carpellary/ poly or multicarpellary); syncarpous (when all carpels are fused) or apocarpous, ovary-superior or inferior or semisuperior; number of locules (uni/bi/tri/tetra/penta/multilocular); placentation (arrangement of placental bearing ovules in the ovary) like marginal, basal, axile, free, central, superficial, parietal); number of ovules in each locule; any special character of style and stigma.

Fruit : Type of fruit.

Floral Formula (FF)

Floral Diagram (FD)

1. **Floral formula.** It is a symbolic notation of floral characters to provide information about : (1) number (notation) of floral parts in each whorl of a flower, (2) Position of the floral parts, (3) Cohesion and adhesion of floral parts, (4) Symmetry of the flower, (5) Sexuality of the flower

It cannot explain the type of aestivation in floral parts; relationships among various floral parts; type of placentation in ovary, number of locules in the ovary, fixation of stamens, lobes in anther, shape of petals and sepals, colour of flower, extrorse/introrse condition of stamen etc.

2. V. S. (vertical section) of flower (section of flower in antero-posterior plane) provides information about insertion of floral leaves on thalamus, shape and size of the different types of floral organs, fusion of different parts, fixation of anthers and number of ovules and placentation etc.

3. The following symbols are used for *floral formula* :

Br — Bracteate

Ebr — Ebracteate (no bract)

Brl — Bracteolate ; Ebrl — Ebracteolate

⊕ actinomorphic (radially symmetrical)

+, ∘|∘, %, ⦶ zygomorphic (bilaterally symmetrical or symmetry of one plane), ☿ Bisexual or perfect or intersexual or Androgynous/Hermaphrodite

♀ unisexual pistillate (female) ; ♂ unisexual staminate (male)

N Neuter (no sex)

Epik — Epicaly (hypocalyx)— a whorl of floral leaves outside calyx in Malvaceae

K — Sepals or calyx ; C — Petals or corolla ; P — Perianth (tepals) ; lod — Lodicules

A — Androecium/Stamen ; G — Gynaecium/Carpel/Pistil

∞ — indefinite/numerous (number more than 5)

Std — Staminode (non functional/sterile stamen)

$\overset{\frown}{C\ A}$ epipetalous stamen *i.e.,* stamen attached to Petal

represented by an arc on the anterior side opposite to mother axis while the bracteoles by small arcs on both lateral sides.

In floral diagram, the symbol of symmetry ⊕ or ϕ is placed on posterior side as mother axis. Bract is drawn on anterior side, ovary in the centre, stamens outside ovary; corolla outside stamens and calyx on outer most side.

Interpretation of a FF

1. Br, Ebrl, ⊕, ⚥, $K_{(5)}$, $\overset{\frown}{C_{(5)}\ A_5}$ $\underline{G_{(2)}}$

The formula interprets that the flower is bracteate, ebracteolate complete (as all 4 whorls of calyx, Corolla, stamens and carpels are present), actinomorphic (⊕), hermaphrodite (⚥), Pentamerous, hypogynous (ovary is superior as shown by putting a line below G). It has 5 fused sepals, 5 fused petals, 5 polyandrous, epipetalous stamens and 2 fused (syncarpous) carpels with superior ovary.

2. Br, %, ⚥, $k_{(4/1)}$ $C_{(1/4)}$, A_{2+2} $G_{(\bar{2})}$

It interprets as — bracteate, zygomorphic, hermaphrodite, complete, epigynous (ovary is inferior as shown by putting a line above the G). There are 5 sepals in 2 lips; 5 fused petals fused in 2 lips — upper lip of 1 petal and lower lip made up of 4 petals. There are 4 polyandrous (free) stamens. Gynaecium is bicarpellary, syncarpous, ovary inferior.

1. Brassicaceae (= Cruciferae)*

Commonly called mustard family; *plants predominantly* herbs and sulphur smelling being rich in sulphur rich glucosides like sinigrin and hence are pungent; *Stomata* crucifer type with 3 subsidiary cells; Flowers *tetramerous*, mostly yellow; petals 4 polypetalous, *cruciform* type with distinct limb and claw and arranged diagonally in a cross like manner; stamens 6, polyandrous, *tetradynamous* (2 outer small and 4 inner large), dithecous, nectaries at the base of stamens; carpels 2 placed *transversely* syncarpous, ovary superior, unilocular but becomes bilocular due to be development of false septum called *replum** (placental ingrowth) that helps in dehiscence of fruits, placentation parietal; *Fruit* is siliqua (silicula in *Iberis*). The characteristic secretory cells containing *myrosin* are found which hydrolyse sulphur containing glucosides into glucose and isothiocyanates (mustard oil). Thiocyanates and isothiocyanates are responsible for pungent flavour of mustard cabbage, turnip and radish.

F.F. Ebr, ⊕, ⚥, K_{2+2}, $C_{\times 4}$, A_{2+4}, $\underline{G_{(2)}}$

In Candytuft, 2 petals are larger and 2 are smaller and therefore flower is zygomorphic (ϕ or ∘|∘ or % or ∅); nectaries are 4 in *Brassica* and 2 in *Raphanus*; outer 2 stamens are introrse and inner 4 are extrorse. Petals are absent in *Lepidium*.

Important plants of economic importance : This family is known for its vegetables or oil yielding plants.

(i) *According to ICBN, the name of the family should be ended with suffix *aceae* to an included genus.
(ii) The myrosin enzyme hydrolyses glucosides into glucose and different isothiocynates (mustard oil).
(iii) Oil and oil cake of rape seed and mustard contain glucosinolates which are antinutritional and have adverse effects on our growth and development.
(iv) Yellow colour of mustard oil is due to allyl isothiocyanate.
* Replum is formed by two ribs of ventral suture of syncarpous ovary.

1. *Food yielding plants* : (i) apical bud of cabbage (*Brassica oleracea var. capitata*), untipe, compound corymb inflorescence of cauliflower (*B. oleracea var. botrytis*), fusiform roots leaves and fruits of *Raphanus sativus* (radish), napiform root of turnip (*B. rapa*) and fleshy stem of knol-khol (*B oleracea var. Caulerapa*) are used as vegetables. *It is important to note that patients of goiter should not eat cabbage, cauliflower and radish as they remove iodine of body.*

2. *Oil yielding plants* : seeds of yellow mustard (*B. campestris var. Sarson*), but now called *B. napus* var. *glauca*. Indian mustard (Rai— *B. Juncea*), Black mustard (*B. nigra*) and toria (*B. campestris* var. *toria* (now called *B. natrus var. napus*)) and Tara mira (*Eruca sativa*) are used for the extraction of oil used in cooking, massaging the body and burning. Oil cake is used as cattle feed.

3. *Ornamentals* : Stocks (*Mathiola*), Candytuft (*Iberis*), Wall flower (*Cherianthus chein*), basket of gold (*Alyssum*), Honesty (*Lunaria*).

4. *Capsella bursapestoris* (Shepherd's purse)— a commonly used plant in embryology. Its embryo has largest codyledons.

5. *Arabiadopsisthaliana* (Drosophila of plant kingdom) is widely used in genetic research. Its genome among plants is smallest. It is also used for mouth sore.

6. Seeds of *Brassica juncea* (Rai), *B. nigra* (Black mustard) and *B. alba* (White mustard) are used in pickles.

2. Malvaceae

Commonly celled Malva family/cotton family/china rose family; plant parts with mucilage cells and hairy growth leaves stipulated. Inflorescence solitary axillary, flowers large, showy, *pentacyclic*, an additional whorl of 3-9 leafy structures is present outside calyx, called *epicalyx* (hypocalyx) which is modification of bracteoles (absent in *Sida* and *Abutilon*); Petals 5, large, contorted (*twisted*); stamens ∞, epipetalous, *monoadelphous* (all stamens of a flower fuse by their filaments to form a single staminal tube), anthers *monothecous*, reniform without connective, pollens spiny; carpels 5 to ∞, syncarpous, ovary superior, penta to multilocular with axile placentation; fruit carcerulus in *Abutilon*, *Malva*, *Althaea*, Otherwise capsule.

F.F. Br, $\oplus$, ⚥, $Epik_{3-9}$, $K_{(5)}$ C_5 , $A_{(\infty)}$, $G_{\underline{(5-\infty)}}$

Important useful Plants

(i) *Fibres* : (a) *Gossypium hirsutum* (long stappled american cotton variety), *G. indicum*, *G. herbaceum* (short stappled asian cotton varieties) seed coat is tomentose (hairy) and bears two types of surface fibres — long lint and short fuzz. Lint fibres are rich in cellulose and used commercially. Mercerised cotton is obtained after treating cotton fibres with NaOH. In making absorbent cotton, surgical cotton used by surgeons/doctors fatty substances are removed from cotton.

(b) Deccan hemp/Madras Hemp/Kenaf/Patsan (*Hibiscus cannabinus*)— secondary phloem of stem is source of bast fibre used to make fish nets and ropes.

(c) *H. subdariffa*— stem is source of fibres.

(ii) *Oil* : Cotton seeds are source of cotton oil and oil cake (cattle feed); seed oil of *Abelmoschus moschatus* (musk mallow) used as flowering agents as it has musk like smell.

Cotton is the source of oil, oil cake (cattle feed) and fibres.

(iii) *Ornamentals* : *Althaea* (Hollyhock), *Malva*, *Hibiscus rosasinensis* (china rose/shoe flower), *Thespasia populnea* (umbrella/Portia tree).

(iv) *Medicinal plants* : Seeds of *Malva sylvestris* (Khatmi/mallow) for hoarse throat; bark of *Thespesia* for scabies.

(v) *Vegetables* : Capsular fruits of okra (lady's fingers) *Abelmoschus esculentus* are used as vegetable.

(vi) Petals of shoe flower/china rose are used for polishing shoe and colouring food articles.

(vii) **Bombax ceiba* — wood is used to make toys, pencils and match splints.

(viii) *Ochroma *(Balsa wood)*— lightest wood.

3. Leguminosae (= Fabaceae)

Commonly called legume family; 4th largest (after compositae and orchidaceae, gramineae) and 2nd most valuable family and provides maximum timber. Leaf base pulvinus and usually pinnately compound, carpel one, unilocular with marginal placentation, *odd sepal is anterior*, fruit legume; flower perigynous, gynophore present. On the basis of characters of *Corolla* (Symmetry of flower, type of petals and their fusion and aestivation) and *androecium* (number and arrangement), this family is divided into 3 sub families which now-a-days are treated as separate families.

Papilionaceae (= Papilionoideae)	*Caesalpiniaceae* (= Caesalpinoideae)	*Mimosaceae* (Mimosoideae)
1. Plants mostly herbs	Shrubs	trees
2. Leaves imparipinnate compound	Paripinnate compound	bipinnate compound
3. Roots nodulated	may be nodulated	rarely nodulated
4. Petals 5, unequal, *Papilionaceous* butterfly type	Petals 5, unequal with ascending imbricate	Petals 4 or 5 equal, valvate
5. Odd Petal largest, posterior and outer most called vexillum (standard). It covers two wings (Alae) which in turn covers two small, fused petals called keel (carinae)	Odd petal smallest, posterior and innermost	All petals are equal
6. Stamens 10, diadelphous (1+ (9)) or 5+5 or monoadelphous (10 or 9)	10, polyandrous in two whorls of 5 each, some are staminodes.	A = C or 2C* (4, 8 or 10) or numerous (∞) free or monoadelphous
7. Symmetry of flower $\circ\vert\circ$	$\circ\vert\circ$	⊕
8. Fruit — Pod F.F. Br, ϕ, ⚥, $K_{(5)}$, $C_{1+2+(2)}$, $A_{1+(9)}$, G_1	Pod/lomentum Br, ϕ, ⚥, K_5, C_5, A_{5+5}, G_1	lomentum Br, ⊕, ⚥, $K_{(4)\text{ or }(5)}$, $C_{4\text{ or }5}$ 5, $A_{4\text{ or }8\text{ or }10}$, ∞ or (∞), G_1

Exceptions : Papilionaceae

(a) Stamens 10, free in *Sophora*; 5 + 5 in *Aeschynomene* ; 10 and monoadelphous in *Erythrina, Arachis, Crotalaria* 9, monoadelphous in *Dalbergia.*

*Now placed under family Bombacaceae.

* Four largest families compositae (950 g); orchidaceae (735 g), gramineae (620g) and leguminosae (600 g) in order of genera.

*A = C *i.e.*, number of stamens equal to petal number.

A = 2C *i.e.*, number of stamens double the number of petals.

(b) *Mimosaceae* : stamens ∞, free in *Acacia*; ∞ and monoadelphous in *Albizia* and *Pithecolobium*; 4 and free in *Mimosa*, 1.

(c) Flower is Tetramerous (Sepals 4, Petals 4, Stamens 4) in *Mimosa*.

Economic Importance

1. *Papilionaceae* This family is known for protein rich pulses. They contain all protein amino acids but poor in sulphur containing amino acids like methionine and cysteine. It also provides fodder, fibre, timber and oil. (i) *Pulses* : Chick pea or Gram (*Gcer arietinum*). It is india's largest cultivated pulse crop and India produces 90% of total gram. Its seeds have 23% protein, Soyabean* (*Glycine max*), protein 42%. It is called vegetable meat, abo used as source of soybean oil. Pea (*Pisum sativum*). lentil/masoor (*Lens culinaris*). Moong/Green Gram (*Vigna* (= *Phaseolus*) *aureus* = radiata); Black gram/urd (*Vigna* (= *Phaseolus*) *mungo*); mat bean/moth (*V* = *P*). *aconitifolia*); Pigeon pea / Red gram/ Arhar (*Cajanus cajan*).

Seeds of *Lathyrus sativus* (Khesri / grass pea) are mixed in gram/Red gram. They contain a neurotoxin BOAA (β– oxalylamino alanine). Which on consumption causes crippling disease/**Lathyrism** (a type of muscular dystrophy)

2. *Vegetables*. *Dolichos lablab* (= *Lablab purpurens*) (Sword Bean). *Trigonella foenum– graceum* (methi/fenugreek), *Canavalia gladiata* (Jack bean world bean). *Vigna unguiculata* (lobia/cow pea). *Vicia faba* (Bankla). Vigna (= *Phaseolus*) *vulgaris* (french bean/Rajmah). *Vigna lunatus* (Lima bean). *Cyamopsis tetragonoloba* (cluster bean/Gwar)

3. *Oil*. (a) Cotyledons of seeds of *Arachis hypogea* (Groundnut/Peanut) are source of ground nut oil. India is the largest producer of ground nut in world though it has America its primary home. Flowers are cleistogamous. Fertilization occurs outside the soil but fruits develop in the soil. This is celled *Geocarpy*. It is due to auxin hormone. One kg of seeds yields 6000 kcal of energy as compared to 2000 kcal contained in the meat of the same weight. Seeds yield **oil** (43–50%) and **Proteins** (31%). Oil cake left after extraction of oil is used as **cattle feed** and manure. (b) Seeds of *Glycine max* yield soybean oil. (c) Seeds of *Pongamia* yields pongam oil used in soap and leather industry.

4. *Fodder*. This family provides **maximum forage** for cattles. Lucerene/Alfalfa (*Medicago sativa*) is worlds greatest forage crop given to horses but not to milch cattles; clover/Barseen (*Trifolium alexandrianum*)– best for milch cattles. Shaftal (*T. resupinatum*). Senji/Indian clover (*Melilotus indica*), Guar gum (*Cyamopsis tetragonoloba*).

5. *Timber Dalbergia sissoo* (Indian red wood/Shisham). *D.latifolia* (Rose wood of India). *Pterocarpus santalinus* (Indian red sandal wood tree); *Erythrina* (India coral tree), *P. marsupium* (Indian kino tree).

6. *Dyes*. *Santalin red dye* from *Pterocarpus santalinus* wood; yellow orange dye from flowers of *Butea monosperma* (Dhak; Tesu, Palas *fleme of the forest*) as its red flowers during blossom given appearance of fire in the forest); Blue dye from the leaves of *Indigofera tinctona* (Indigo/Neel plant).

7. *Fibres*. Secondary phloem of stem of Sunnhemp (*Crotalaria juncea*).

8. *Soil fertility*. Roots of plants of this family are nodulated and contain *Rhizobium*, a nitrogen fixing symbiotic bacterium (except nodules in root of *Trifolium alexandrium* formed by *Nostoc* which fix atmospheric nitrogen into NH_3 and increase the fertility of the soil. *Crotalaria, Sesbania, Cyamopsis* are used as green manure. *Sesbania rostrata* has two nitrogen fixing bacteria one *Rhizobium* in roots nodules and *Aerorhizobium* in their nodules.

9. *Medicinal Plants*. Roots of Liquorice = Mulaithi (*Glycyrrhiza glabra*) are used in sore throat. Glycyrrhizin, a glycoside in root is 50 times sweeter than sugar. Flowers of *Alhagi* in piles. Seeds of

*Soybean gives pulses, oil and milk.

Psoralea corylifolia (Babchi/Khatmi) for leucoderma. Glasses made of wood of *Pterocarpus marsupium* (Indian kino tree/vijayasar) are used to keep water used by diabetes and dried roots of *Krameria triandra* (Krameria) for diarrhoea. *Sesbania grandiflora* (agast)— juice of flowers is useful in eye sight.

10. *Other plants of importance.* (a) *Abrus precatorius* (crab's eye, jwellers weight, ratti, Indian licorice)— seeds of this plant were used by Jewellers for weighing gold. The weight of each seed is constant and equal to one ratti (0.125 g). Seeds also contain a poisonous protein abrin which inhibit protein synthesis as well as bring abortion. (b) Leaves of *Butea* (Dhak) are used as plates for keeping food/chat etc. (c) Cork obtained from pith of Indian cork plant or pith plant/sola (*Aeschymonene aspara*) is spongy and used in making toys and solar hats. (d) Guar gum is obtained from seeds of *Cyamopsis tetragonoloba*. Gum tragacanth from *Astragalus gummifer*. (e) *Desmodium gyrans* (Telegraphic plant) shows autonomic variation movements by moving its two lateral leaflets up and down (f) roots of *Derris elliptica* yield a **natural insecticide rotenone**. (g) *Lathyrus odoratus* (sweet pea), *Clitoria*, *Erythrina* (coral tree), *Lupinus*, *Sophora* are cultivated in gardens.

2. Caesalpiniaceae

1. *Trees* : *Cassia fistula* (Amaltas), *Intsia hookeri* (Iron wood of Andaman) *Delonix regia* (Gulmohar), *Tamarindus indica* (Imli = Tamarind), *Bauhinia* (Kachnar), *Saraca indica* (Ashok) *Hardwickia binata*. *Cassia* : It includes herb (*C. tora*) shrub (*C. sophora*) and trees (*C. fistula*).

2. Dyes : Heartwood of *Haematoxylon campechianum* (logwood or patang) yield a red nuclear dye haematoxylin; Heartwood of *Caesalpinia sappan*) gives a red dye (abir/Holi Ka Gulal).

3. *Medicines* : Bark of *Saraca indica* (Ashok) for menstrual problems, leaves and pods of Indian senna (*Cassia angustifolia*) are purgative, Juicy fruits of tamarind Imli (*Tamarindus indica*) are rich in tartaric acid and used to make sauces. Pods/Pulpy seeds of *C. fistula* are used in digestive disorders.

4. Flower buds of *Bauhinia variegata* (kachnar/camels' foot tree) are eaten as vegetable.

5. *Parkinsonia aculeata* (Jerusalem Thorn tree/vilayati kikar) has smallest phyllodes.

6. Bark of *Caesalpinia*, *Cassia* and *Bauhinia* are source of **tannins.** Violin bows are made of wood of *Caesalpinia echinata*.

7. *Cassia fistula*, *Caesalpinia pulcherrima* (seacock flower) are ornamentals.

3. Mimosaceae

It provides maximum timber and tannins.

Trees : *Acacia nilotica* (= *A. arabica* (babool/Kikar), *Albizia lebbek* (Silk flower tree/Siris) *Xylia xylocarpa* (Iron wood of India used for ships and bridges and railway slippers), *Enterolabium saman* (rain tree); *Acacia catechu* (Cutch), *Prosopis juliflora* (used as wind break to check soil erosion/ spread of desert. *Pithecolobium dulce* (Jungle Jalebee), *A. melanoxylon* (Australian black wood), *Leucaena leucocephal a* plant recommended in social forestry for fire wood.

Pods of *Acacia rugata* (= *A. sinuata*) (Shikakai/Soap Pod) contain saponin and used for washing hair and in making shampoos.

Cassie perfume is prepared from flowers of *A. farnesiana*.

Catechu/Cutch/Katha is obtained from heart wood of *A. catechu*. It is used in medicines, industries besides an ingredient of betel (Pan). It also gives olive brown dye for dyeing silk.

Mimosa pudica (Touch me not/sensitive plant) shows seismonastic movements.

Tannins are obtained from barks of various species of *Acacia* and *Albizia*.

Pod of *Entada* is 1m in length. It is *largest pod*. Its seeds are used as substitute for soap.

Sweet and juicy aril of Seeds of *Pithecolobium dulce* (Jungle Jalebi) are edible.

Neptunia is called aquatic touch me not. Its fruits are edible.

Gum is obtained from *A. arabica* (kikar gum) and *A. senegal* (gum arabic).

Twigs of *A. arabica* (= *A. nilotica*) are used as tooth stick (Daatun).

4. Compositae (= Asteraceae)

Commonly called Sunflower, largest family of plant kingdom, respresented by 950 genera and 20000 species plants mostly herbs stem with latex/oil ducts and most evolved and advanced among dicot. Inflorescence *Capitulum* (racemose head) which is most advanced infloresence as a single insect can polinate all the flowers. Here the thalamus is flattened called receptacle bearing small sessile flowers (called florets) in centripetal manner. These florets are surrounded by an involucre of bracts. The whole inflorescence *looks like a flower**. It is of two types (i) *Homogamous* (all florets are alike and either tubular, ⊕, *e.g.*, *Ageratum* or ligulated, $\cdot|\cdot$, *e.g.*, *Sonchus*. (ii) *Heterogamous* (all florets are of 2 types— (a) ligulated (strap like), $\cdot|\cdot$, pistillate or neuter, called *ray florets** and present towards periphery (b) tubular, ⊕, ⚥, called *disc florets* and present towards centre), *e.g.*, *Helianthus*. Sepals are reduced modified as scales (*e.g.*, *Helianthus*) or hairy **Pappus** (*e.g.*, *Tridax*, *Sonchus*, *Dandelion*) or bristles (*e.g.*, *Carthamus*); petals ligulated or tubular: stamens 5, epipetalous and Syngenesious (synantherous), $G_{(\bar{2})}$, unilocular, basal placentation, stigma bifid feathery, *Pappus* remains attached to the cypsela fruit, act as parachute and help in dispersal.

F. F. *Disc floret* : Br, ⊕, ⚥, K_{2-3} sclaes/pappus, $C_{(5)}$, $A_{(5)}$, $G_{(\bar{2})}$

Ray floret (in heterogamous head) Br, $\cdot|\cdot$, ♀ or neuter, K_{2-5} scales or pappus, $C_{(0/3)\text{ or }(0/5)}$, A_0 $G_{(\bar{2})}$ or G_0

Ray floret in homogamous head *e.g.*, *Sonchus*.

Br, $\cdot|\cdot$, ⚥, K_{pappus}, $C_{(0/5)\text{ or }(0/3)}$ $A_{(5)}$, $G_{(\bar{2})}$

Important Plants

Ornamentals : This family provides maximum flowering plants. *Aster*, *Brachycoma*, *Calendula*, *Chrysanthemum*, *Cinneraria*, *Gerbera*, *Dahlia*, *Helianthus annuus* (Sunflower), *Tagetus* (Marigold), *Bellis* (Daisy), *Helichrysum* (Paper flower), *Zinnia* (youth and old age). *Cosmos*, *Centaurea*, *Dimorphotheca*, *Ceutaurea* (Sweet sultan), *Gailardia*.

Weed : *Parthenium hysterophorus* (carrot grass/congress grass), a most nasty weed, came into India from USA during congress rule in 1950's alongwith wheat. Its pollen grains cause skin allergy; Rugweed (*Ambrosia artemissifolia*) its pollens cause hay fever.

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* Ray florets are always unisexual pistillate or neuter in heterogamous head inflorescence. In homogamous head, these are bisexual. Modifications and reduction in number of floral parts are advanced characters. Large number of floral parts and their spiral arrangement are primitive characters.

* Basal placentation is most advanced. In *Echinops*, capitulum is compound.

* Sunflower is not a flower but an inflorescence as it has many florets (flowers) of two types arranged centripetally and surrounded by an involucre of bracts.

* In India, compositae is represented by 1000 species.

Oils. Seeds of *Helianthus annuus* (Sunflower) are source of sunflower oil rich in unsaturated linoleic acid; seeds of *Carthamus tinctorius* (Safflower) yield Safflower/Kusum oil containing 73% PUFA (Polyunsaturated fatty acids) its good for heart patients. *Arnica montano* is used in Arnica hair oil.

— Leaves of *Lactuca sativa* are used as Lettuce/Salad.

— Roots of chicory (*Cichorium intypus*) after roasting and crushing are used as adulterants in Coffee.

— Extract of leaves of *Eclipta prostrata* (Bhrangraj) and *Wedelia chinensis* are used in hair oil.

— *Calendula* has healing properties. **Pyrethrum** a natural insecticide, is obtained from inflorescence of *Chrysanthemum cineranaefolium*. *Santonin* (antiworm drug) is obtained from *Artemisia maritima*, stem tubers of *Helianthus tuberosus* (Jerusalem artichoke) are edible. *Xanthium strumarium* (cocklebur) is used in photoperiodism experiments. *Jurinea* its extract of roots is used as incense (commericial source of Dhoop).

5. Solanaceae

Popularly called potato family, provide maximum vegetables, vascular bundles bicollateral in stem. Flowers pentamerous, infundibuliform (funnel like) in some sepals persistent and accrescent (enlarge with fruit), petals 5, gamopetalous, induplicate valvate, Stamens 5, polyandrous, *conniving* (appears to be fused), epipetalous, $G_{(2)}$, bilocular, Axile placenetation; ovary obliquely placed due to rotation of posterior ovary towards right side and anterior carpel to left side by 45°, placenta highly swollen, ovules are maximum per locule in this family, fruit capsule or berry.

F.F. $Br, \oplus,$ ⚥, $K_{(5)}, \widehat{C_{(5)}, A_5}, G_{(2)}$

Important Plants

Vegetables/fruits : Stem tubers of Potato (*Solanum tuberosum— international vegetable, most common tuberous crop and a gift of new world to old world.* Brinjal (egg plant/mustard apple, *Solanum melongena* tomato (*Lycopersicon lycopersicum*). Chillies/green pepper (*Capsicum annuum*). Seeds contain oleoresin which gives pungency; Bell (Shimla) Pepper (*C. frutescens* var. *grossum*), raspberry. (*Physalis peruviana*, rich in vitamin C). Vodka (alcoholic beverage) is made from potato tubers.

Medicinals : (a) Atropine and belladonna are obtained from leaves and roots of *Atropa belladona* (deadly night shade). Atropine is widely used in eye disorders and eye sight testing; belladona plaster is used to cure boils. (b) *Datura stramonium* (Jimson's weed/Thorn apple) its leaves and fruits yields (*stramonium* used an alkaloid in bronchitis. (c) Dulcamara is obtained from *Solanum dulcamara*. (d) Leaves and flower of *Hyoscyamus niger* (Henbane) contain alkaloids like *hyoscyamine* (main alkaloid of this family) *Scopolamine* which are sedative. *Scopolamine* is used as *Truth drug* in crime detections. (e) Aswagandha (*Withania somnifera*) is obtained from roots and used in hiccup, cough and rheumatism. *W. coagulans* fruits are used to *Coagulate the milk.*

Ornamentals : *Petunia, Cestrum nocturnum* (Night Jasmine/Rat Ki Rani), *C. diurnum* (Din ka Raja) *Schizanthus* (Poorman's orchid/butterfly flower), yesterday, today, tomorrow. (*Brunfelsia hopeana*)— its flowers are white but change to blue colour.

Fumitories/Masticatory. Leaves of *Nicotiana* (*N. tabaccum* and *N. rustica*) are source of tobacco, which is chewed and smoked. An alkaloid, *Nicotine* obtained from tobacco leaves which is used to make a natural insecticide nicotine sulphate.

6. Labiatae (= Lamiaceae)

Commonly called mint family; stem/inflorescence axis is squarish; inflorescence *verticillaster**, sepals and petals both are bilabiate (*bilipped*) O, with wide opening between upper and lower lips; stamens 2 or 2 + 2 (*didynamous– 2 small and 2 large)*, versatile, epipetalous, style *gynobasic*, $G_{(2)}$, bilocular, which becomes teralocular due to development of false septum. Axile placentation, a nectary disc present below ovary; fruit carcerulus/nutlets.

F.F. Br, O, ⚥, $K_{\text{bilipped (2/3) or (1/4)}}$, $C_{\text{bilipped (3/2) or (4/1)}}$, $A_{2 \text{ or } 2+2}$, $G_{(2)}$

Important Plants

Ornamentals : *Salvia, Coleus, Lavendula, Thymus.*

Medicinals . *Mentha viridis* (= *M. arvensis*)— mint/Pudina, *M. piperata* (Pepper mint/Menthol), *Thymus vulgaris* (Thymol) *Ocimum sanctum* (basil/Tulsi), *O. basilicum* (Kali tulsi). Thymol is used in tooth paste and menthol in cough lozenges.

Perfumery : Lavender oil from flowers of *Lavendula*, rosemary oil from leaves of *Rosmarinus* and Patchouli oil from leaves of *Pogostemon.*

7. Liliaceae

Commonly called lily family; belong to *monocotyledons*; plants usually herbs with underground bulbs and radical leaves, *perianth* (calyx and corolla undifferentiated) biseriate (2-whorled) and petaloid; flower hypogynous, ⚥ and *trimerous*; $G_{(3)}$, trilocular, Axile placentation, stamens 6 in 2 whorls of 3 each, polyandrous may be epiphyllous, stamens dorsifixed, fruit capsule or berry, infloresence *scapigerous i.e.*, flowers are borne on scape.

F.F. Br, ⊕, ⚥, $P_{3+3 \text{ or } (3+3)}$, A_{3+3}, $G_{(3)}$

Important Plants

1. *Trillium* has largest chromosome of 30 μm length.
2. In *Smilax, leaves show reticulate venation* and its flowers are unisexual.
3. Roots of *Smilax* yield *sarasparilla* like drug for leprosy, piles and purification of blood.
4. Fasciculated root tubers of *Asparagus racemosus* (satawar) are edible and have medicinal value in rheumatism, *A. adscendens* (safed Moosli) – roots are used in diarrhoea.
5. Bulbs of onion (*Allium cepa*, edible part is leaf bases rich in glucose) and *A. sativum* (garlic) are used as vegetables and have medicinal value. The *acrid taste of onion is due to allyl propyl sulphides and of garlic due to allyl disulphide. Eye tearing on cutting of onion is due to volatile thiosulphates.*
6. Tulips (*Tulipa*), lilies (*lilium*) *convallaria* (lily of valley), *Sansevieria* (mother in lanis tongue), *Cocoloba*, *Asparagus* are ornamentals.
7. Corm of *Colchicum autumnale* is source of an alkaloid *colchicine* used to induce polyploidy; *C. luteum* is used in the treatment of gout and rheumatism.
8. Resin from leaves of *Xanthorrhoea* is source of sealing wax.

*Verticillaster is a special inflorescence in which a cluster of flowers borne on a dichasial cyme ending in scorpioid cyme forming a condensed whorl on either side of node.

9. *Yucca* (Dagger plant), *Agave* (century plant flowers once in 40 to 60 years), *Dracaena* (Dragon plant) shows secondary growth.

10. Fleshy leaves of *Aloe vera* (Shritkumari) is source of *Aloin* (Jamalghota) used as purgative, mosquito repellent and in cosmetics.

11. *Fritillaria* was first plant in which double fertilization was studied.

12. *Gloriosa superba* (Glory lily)— Leaf shows tendrillar leaf tip; roots are poisonous.

13. Fibers from leaves of *Sanaeviera, Agave, Yucca* and *Phormium tenax* (Newzealand hemp).

8. Gramineae (= Poaceae)

Commonly called cereal/grass family, highest evolved/most advanced family due to reduction and modification and floral parts; monocot family, third largest family after compositae and orchidaceae but in Indian flora, they constitute the largest family. Flower *trimerous*, growth by intercalary meristem, inflorescence is compound (spike of spikelet/panicle of spikelet) in which unit of inflorescence is not a single flower but a group of usually 3–5 (1–8) sessile small flowers (florets) called *spikelet*. Bract is modified into Lemma (Inferior Palea) that bears awn for defense; bracteoles modify into palea (Superior Palea); perianth is reduced to 2–3 boat shaped membranous *lodicules*. Glumes cover the inflorescence till maturity. Stem jointed and terminates in inflorescence called *culm*; may be hollow or solid with intercalary meristem. Leaves sessile, distichous, ligulated with sheathing leaf base; stamens 3 to 6, *divaricate versatile*, $G_{\underline{1}}$ or *$G_{(3)}$ by some authors) unilocular with basal placentation, stigma bifid lateral and feathery (plumose); *Style absent (except maize) fruit — one seeded fruit called *caryopsis* (grain) and endospermic.

F. F. Br (Lemma), Brl (Palea), ⚥, φ, P_{2-3} lodicules, $A_{3 \text{ or } 3+3}$, $G_{\underline{1}}$ or $G_{(3)}$

Important Plants

Gramineae is the 3rd largest but economically most valuable family as it provides cereals and millets.

Cereals are one seeded fruit called **caryopsis**. They are rich in carbohydrate, deficient/poor in *lysine* and *tryptophan*. They lack vit A except yellow maize. (1) **Wheat** (old world gift to new world and chief cereal of temperate countries, most acreage crop of India). (a) *Allohexaploid wheat* (6x = 2n = 42) — *Triticum vulgare* (= *T. aestivum*), called bread wheat, rich in gluten and good for bread/roti, has 3 different genomes. (b) *Tetraploid wheat* (4x = 2n = 28). *T. durum*, called emmer or Durum or Macroni wheat, used for making noodles and macroni. (c) Diploid wheat (2x = 2n = 14). *T. monococcum*, called einkorn wheat. (2) **Rice** (*Oryza sativa* — *widest and largest cultivated crop* of world, major tropical cereal crop, India's principal crop, used for making sake beverage in Japan by *Aspergillus oryzae*. (3) **Maize/Corn** (*Zea mays*)— highest yielding cereal crop, tallest cereal crop, new world gift to old world, grains are source of commericial starch, popcorn, flakes, cakes, oil, custard powder, corn sugar etc. Yellow maize is rich in thiamine but poor in tryptophan and lysine. Maximum heterosis (hybrid vigour) is exploited in maize. It is most widely used plant in genetic research whose genetics is fully known. (4) **Barley** (*Hordeum vulgare*) is oldest cereal crop under cultivation ; grains are source of *malt* after fermentation. Which is used to prepare beer, bournvita etc. (5) **Oat** (*Avena sativa*). (6) **Rye** (*Secale cereale*). (7) Small, rounded cereals are called *millets*. These are minor cereals as used by few people. These are warm weather cereals/cereals of tropics *e.g.*, Great millet/

* Style in maize is largest in plant kingdom.

*Gynaecium in Gramineae is actually tricarpellary, syncarpous, superior. All the three carpels get fused at very early stage of development forming only one chamber with a single basal ovule.

Jowar (*Sorghum vulgare*), Pearl millet/Bajra (*Pennisetum typhoides*), Wye or *Triticle* (man made synthetic wheat made by crossing Rye (*Secale cereale*) X wheat (*Triticum vulgare*) by Muntzing, Finger millet / Ragi (*Eleusine coracana*) is hardest millet and its grains are free from pericarp. It is main cereal of south India; Kangni (*Setaria italica*), *Echinochloa colona* (sawank). (8) **Bamboo** (*Bambusa*) (hollow stem), *Dendrocalamus* (solid stem) are two main bamboos; called *poormans' wood, tree grass*, they flourish in tropical rain forests, used in making cots, lances, paper etc. Dendrocalamus is largest bamboo with diameter of 25 cm. (9) Stem of *Arundodonex* and *Arundinaria* is used to make flutes. (10) Job's tear (Coix) its grains are used as beads for making ornaments. (11) Stem of sugarcane *Saccharum officinarum* yield cane sugar ($C_{12}H_{22}O_{11}$). Bagasse is (crushed canes after removal of juice) is used as fuel, making paper, board etc. *Molasses* (stem juice left after crystallization of sugar) is used in fermentations to get alcohol. (12) Khus oil and khus mats/curtains are made out of roots of vetiver grass (*Vetiveria zizanoides*). Lemon grass (*Cymbopogon citratus*), Ginger grass (*Andropogon odoratus*). *Citronella* grass (*Cymbopogon nadrus*) are romatic grasses and provide perfumes. (13) *Erianthus arundinaceus* (Sarkanda)— used to make chairs (Moorah) and leaf fibres for ropes; *E. munja* (moonj)— stem fibres for making baskets, mats and ropes; *Eulaliopsis binata* (Bhabhar) used to make ropes and paper. (14) *Eragrostris* and *Thysanolaena* used to make brooms. (15) *Phragmites karka* (Pora) is used for making writing Pen (Kalam). (16) Forage by shoots of *Sorghum vulgare* (Jowar/Chari) Cynodon, *Pennisetum, Echinochloa, Poa, Setaria, Panicum.*

Rigidity of stem of bamboos is due to sclerenchymatous hypodermis and bundle sheaths, otherwise secondary growth is absent.

FRUIT

A fruit is a characteristic of angiosperms. After fertilization, except ovary, all floral parts wither away, ovary is converted into fruit and ovules into seeds. Thus a true fruit is fertilized and ripened ovary which consists of **pericarp** (fruit wall developed from ovary) and **seeds** (formed after fertilization of ovules). Thus from biological point of view, Tomato, Okra, Gourds, Brinjal are fruits as they develop from ovary, though they are considered to be vegetables by the common man. Fruits are of three basic types : (i) **Eucarps** (= Eucarpic Fruits). They are true fruits formed from superior ovary only having one or more viable seeds and no other floral parts take part in fruit formation, *e.g.*, Grape, Maize, Mango. (ii) **Pseudocarps** (= Spurious fruits or accessory or false fruits). They are fruits generally formed from inferior ovary alongwith adjoining accessory floral parts (sepals/bract/perianth/thalamus and containing one/more viable seeds, *e.g.*, Apple, Pear, Loquat, Pineapple, Mulberry Litchi, Guava, Brinjal. (iii) **Parthenocarps** (Parthenocarpic Fruits) are seedles fruits and formed from ovary without fertilization. They are seedless or if seeds present, they are abortive (non viable or empty), *e.g.*, Banana, Oranges Grapes, Pineapple, Guava, etc.

A true fruit has (i) fruit wall (pericarp) derived from ovary wall. In fleshy fruits, it is differentiated into outer epicarp, middle mesocarp and inner endocarp. (ii) Seeds developed from ovules after fertilization. The biological need of the fruit is the protection of seeds and help in their dispersal.

Types. Fruits are classified into three categories– simple, aggregate and composite *on the basis of number of ovaries and the flowers involved in their formation, nature of pericarp, union of carpels and type of dehiscece.*

Simple Fruits

They develop from single flowers having single ovary (simple or syncarpous compound). According to the nature of pericarp (fruit wall), simple fruits can be **dry** or **succulent**. In Dry fruits, pericarp is dry and undifferentiated.

(A) Dry fruits

They are of three kinds on the basis of dehiscence — achenial, capsular and schizocarpic.

(i) Achenial Fruits

Achenial fruits are simple, dry, **one seeded** *indehiscent fruits* (which donot burst / split open at maturity) and are of six types.

1. **Achene.** It is simple dry, one seeded superior achenial indehiscent fruit in which dry pericarp is free from single seed except at one point. It develops from monocarpellary superior **one ovuled** ovary, *e.g.*, *Mirabilis*.

2. **Caryopsis (Grain).** It is superior achenial one seeded indehiscent fruit in which pericarp is fused with seed coat (testa) completely. It develops from monocarpellary, one ovuled superior ovary, *e.g.*, Wheat, Rice (paddy), Maize, Oat /cereals of Gramineae.

3. **Cypsela (Inferior Achene).** It is inferior achenial, indehiscent one seeded fruit in which pericarp is free from testa but fused with thalamus. It is derived from bicarpellary, one ovuled inferior ovary, *e.g.*, Sunflower. In many plants, cypsela bears persistent hairy **pappus** (modified sepals) for dispersal, by acting as parachute, *e.g.*, *Sonchus, Taraxacum* (Dandelion), *Lactuca*. It is found in members of family compositae.

4. **Nut.** It is a single seeded, single chambered fruit in which the pericarp is hard/woody or leathery. Ovary may be superior or inferior, *e.g.*, Cashewnut, Oak, Chestnut, Litchi, Pista nut, Walnut (previously considered to be drupe). **Walnut** (Akhrot) has a husk like exocarp (thalamus, perianth and bract), woody pericarp and a single seed having two convoluted (lobed) oily edible cotyledons. In Cashewnut, pericarp is stony enclosing two large edible cotyledons and the fruit develops on fleshy thalamus. The nut or acorn of **Oak** bears a persistant cupule of bracts. In Litchi the pericarp is brittle, leathery with spine-like outgrowths and inbetween pericarp and seed is edible, fleshy, white collar like post fertilized outgrowth of funicle at micropylar end called aril. Aril is also found in Nutmeg and *Inga edulis*, Nymphaea (water lilly) yew etc.

*5. **Samara (Simple samara).** It is one seeded achenial winged fruit. The wings are developed from pericarp, *e.g.*,*Ulmus* (Elm), Hiptage, *Holoptelia* (chilbil).

6. **Utricle.** It is an achenial small bladder like fruit, *e.g.*, *Chenopodium*.

(ii) Capsular Fruits

They are simple, dry **many seeded** and *dehiscent fruits*, which on ripening burst automatically to discharge their seeds. Such fruits become dry on maturity. Capsular fruits are of five types:

1. **Legume (Pod).** A many seeded dry fruit derived from superior unilocular ovary which automatically splits up by both dorsal and ventral sutures to release seeds, *e.g.*, *Pea, Abrus*, Beans, Gram.

2. **Follicle.** A many seeded dry fruit derived from superior unilocular ovary which splits up by one suture ((mostly ventral), *e.g.*, Larkspur, *Catheranthus*.

3. **Siliqua.** An elongated cylindrical fruit derived from bicarpellary superior unilocular ovary with parietal placentation and false septum (replum) which dehisces by two valves from base upwards along both the sutures to expose seeds. Seeds are attached to replum, *e.g.*, fruits of Radish, Mustard (*Brassica campestris*)/Cruciferae.

4. **Silicula.** It is a few seeded shortened and flattened (usually as broad as long) siliqua, *e.g.*, Shepherd's Purse (*Capsella bursa-pastoris*), *Iberis* (Candytuft).

* (i) In samaroid, fruit wings are develped from sepals instead of pericarp, *e.g.*, Shorea (sal), *Dipterocarpus*. (ii) In Walnut (Akhrot) cotyledons are hard and ruminate (convoluted) due to ingrowth of endocarp. (iii) Aril of *Myristica* (Nutmeg) is used as spice (Javitri).

5. **Capsule**. It is derived from multicarpellary syncarpous ovary. It is multiseeded simple dry dehiscent fruit. Depending upon the mode of dehiscence, capsules are of the following kinds:

(i) **Porocidal Capsule**. Dehiscence by pores, *e.g.*, Poppy, *Antirrhinum* (Dog Flower), *Argemone*.

(ii) **Denticidal Capsule**. Dehiscence by teeth, *e.g.*, Pink (*Dianthus*).

(iii) **Loculicidal Capsule**. Longitudinal slits opening into loculi/valves, *e.g.*, Lady's Finger (Okra,) Cotton.

(iv) **Septicidal Capsule**. Longitudinal slits opening along septa, *e.g.*, Pansy.

(v) **Septifragal Capsule**. Dehiscence exposes a central axile column containing seeds, *e.g.*, *Datura* (Thorn apple).

(vi) **Pyxidium**. Transverse dehiscence to lift a lid, *e.g.*, *Portulaca*, Cock's Comb (*Celosia*).

(iii) Schizocarpic Fruits

These fruits are in between dehiscent and indehiscent fruits.

They are simple, dry *many seeded* fruits which break up into one-seed indehiscent parts called **mericarps** or one seeded dehiscent parts called **cocci** (singular coccus). They are of five kinds:

1. **Cremocarp**. It is a dry indehiscent two chambered fruit developed from bicarpellery inferior ovary; on maturity. Fruit breaks up into two mericarps which remain attached to central axis or Y shaped carpophore (elongation of thalamus) by means of stylopod, Number of mericarps are equal to the number of carpels, *e.g.*, Coriander, Fennel, Cumin (family Umbelliferae).

2. **Carcerulus**. Fruit breaks up into 3 or more indehiscent mericarps which do not have stylopods, *e.g.*, *Abutilon*, *Althaea*, Garden Nasturtium, *Salvia*, *Ocimum*.

3. **Compound Samara**. The fruit breaks up into two or more winged mericarps, *e.g.*, *Acer* (Maple— two mericarps), *Dodonaea* (three mericarps).

4. **Regma** developed from tri to multicarpellary syncarpous superior ovary. The fruit breaks up into 3 to many dehiscent one seeded cocci, *e.g.*, *Euphorbia*, *Jatropha*, Castor, *Geranium*. In *Geranium* the five cocci remain attached to five hygroscopic styles till the seeds are shaken out of them. In Castor there are 3 cocci.

5. **Lomentum**. It is many seeded, constricted in between the seeds and of two types :

(i) **Lomentaceous Pod**. It is similar to pod or **legume** in origin but is either indehiscent (*e.g* Groundnut) or breaks up into single-seeded parts (*e.g.*, *Acacia*, *Mimosa*, *Entada*, *Igna*, Tamarind).

(ii) **Lomentaceous Siliqua**. It is similar to **siliqua**, *e.g.*, Radish (indehiscent).

(B) Simple Succulent (fleshy) Fruits. They are simple fruits in which pericarp and associated structures become fleshy. The fruits on the basis of nature of endocarp are grouped into three types *viz.*, - berries, drupes and pome.

1. **Berries** (Baccate Fruits). These are fleshy, many seeded in which the fleshy pericarp is differentiated into three parts – outer epicarp, middle thick fleshy mesocarp and inner **endocarp**. Endocarp is papery in Date palm and pulpy in others in which seeds are embedded. The seeds become free from placentae. Berries are of four types:

(i) **Superior Berries** (True Berries) developed from superior ovary and *all the three layers are edible*, *e.g.*, Grape, Tomato, Brinjal, Date*, Papaya, Chillies, betel/Areca nut*.

*Date palm and Areca nut (Betel nut) are one seeded berries.
*In Date palm epi and mesocarp are edible but endocarp is papery and not edible. In betel nut endosperm of seeds is edible.

(ii) **Inferior Berries** (False Berries) developed from inferior ovary, pericarp is fused with thalamus to form exocarp, *e.g.*, Guava (all the three layers with fused thalamus edible). Remains of dry calyx often occur on the tip of fruit.

(iii) **Parthenocarpic Berries** These are seedless berries, *e.g.*, Banana (*Musa paradisiaca*). Banana is also a false berry due to fusion of epicarp with thalamus to form skin (exocarp) which is not edible. Endocarp is less developed and contains unripe or unfertilised ovules. Mesocarp and endocarp are edible parts. Thus, Banana is inferior berry, pseudocarpic and parthenocarpic fruit.

(iv) **Special Berries** like (a) **Balausta**. It is a modified inferior or false berry formed from two rows of fused ovaries. Epicarp is tough and leathery. Mesocarp with infolding and the papery endocarp around each loculus. Seeds have juicy testa. (seed coat) sepals are persistant and present at the top of fruit, *e.g.*, Pomegranate. (b) **Pepo**. Modified inferior berry where mesocarp does not separate from epicarp and *epicarp fused with thalamus, to form* **exocarp** and **seeds do not separate from placentae**, *e.g.*, *Cucumber*, Gourd Melon, Water Melon of cucurbitaceae (c) **Fibrous Berry**. Mesocarp is fibrous while endocarp is fleshy in moist condition, *e.g.*, Betel/Areca Nut (*Areca catechu*). The nut of commerce is the outer part of seed or endosperm. (v) **Hesperidium** is many chambered superior berry (derived from polycarpellary, syncarpous and superior ovary) where each chamber is covered by membranous endocarp. In each loculus are present multicellular juicy hair derived from inner surface of endocarp (also considered placental hair). Mesocarp is thin fibrous while epicarp forms the glandular skin, with oil glands. Epicarp is fused with mesocarp to form rind, *e.g.*, *Citrus* (Orange, Lemon) fruits of Rutaceae (vi) **Amphisarca**. It is a modified superior berry in which the epicarp is woody, mesocarp is fibrous while endocarp and placentae form a pulp, *e.g.*, *Aegle marmelos* (wood apple) and *Feronia* (kaith)

2. **Drupes** (Stone Fruits). Pericarp is differentiated into outer epicarp, middle mesocarp and inner endocarp. The **endocarp is stony**. The fruit contains generally one seed, rarely two (*e.g.*, *Zizyphus*) or three (*e.g.*, *Borassus*). In Mango, epicarp is not edible, mesocarp is pulpy and edible. In Plum, Peach, Cherry and Jujube (*Zizyphus*) both epicarp and mesocarp are edible. In Coconut*, epicarp is thin and **mesocarp is fibrous**. Endocarp bears three eye spots. It encloses a single seed with thin brown testa, oily endosperm, a small embryo and watery fluid (milk of Coconut). In Almond, the edible part is seed, especially its cotyledons. In *Trapa* (Water Chestnut — shingara, previously considered to be a nut), epicarp and mesocarp are thin. Endocarp is thick and **2 spines** on fruit represent sepals. It encloses a single seed with one large and one reduced cotyledon.

3. **Pome** It is an accessory, false fruit or **pseudocarp** where the thalamus is enlarged to form fleshy part. Pericarp is cartilaginous and encloses seed bearing loculi. It develops from inferior ovary, *e.g.*, Apple, Pear, Loquat (Rosaceous fruits). Like other false fruits, the apical part bears remains of different floral parts. Edible part is fleshy thalamus (torus).

Aggregate Fruits

Aggregate fruit is a group of fruitlets developed from a single flower having two or more free (apocarpous) ovaries. Each ovary develops into a fruitlet and all fruitlets developed from a single flower together form an aggregate fruit called etaerio. Depending upon the type of fruitlet, aggregate fruits are of the following types.

1. **Etaerio of Achenes**. (Achenecetum). Individual fruitlets are achenes, *e.g.*, Buttercup (*Ranunculus*), *Clematis*, Rose, Strawberry, (*Fragaria*) *Naravelia*, *Nelumbo* (lotus). In *Clematis* the individual achenes possess persistent hairy styles. In Lotus, the achenes are embedded in spongy

* Coconut (*Cocos mucifera*) fruit (called fibrous drupe) (i) Coir is obtained from fibrous mesocarp, it is used to make ropes. (ii) 3 eye spots on the top of endocarp are bases of styles of three carpels. (iii) Mesocarp is fibrous that gives buoyancy to the fruit in water. (iv) Khopa/Gola is oily cellular endosperm and the source of coconut oil. (v) Coconut milk is degenerated free nuclear endosperm. Thus in coconut fruit, no part of fruit is edible.

thalamus. In Strawberry the fruit has edible fleshy thalamus with small achenes embedded over the surface.

2. **Etaerio of Berries.** (Baccacetum). In *Artabotrys* the individual berries are separate while in Custard Apple (*Annona*) they are fused by their apical part only over an elongated thalamus. Here, the edible part is juicy mesocarp of individual berries, (except apices).

3. **Etaerio of Follicles** (follicetum), *e.g., Calotropis, Michelia, Aconitum, Vinca, Magnolia.*

4. **Etaerio of Samaras.** (Samaracetum), *e.g., Ailanthus.*

5. **Etaerio of Drupes.** (Drupecetum). The individual fruitlets are often called druplets, *e.g.,* Black-berry, Raspberry (*Rubus*).

Composite Fruits (Multiple Fruits)

These fruits develop from entire inflorescence and are always pseudocarpic. They are also called *Infructescence.* They are of 2 types:

Classification of different Kinds of fruits

- **Fruits** (fertilised and ripened ovary)
  - **Simple fruits**
    - **Dry fruits** (Pericarp dry)
      - Capsular Dehiscent (many seeded)
        - Pod
        - Follicle
        - Siliqua
        - Silicula
        - Capsule
      - Achenial Indehiscent one seeded
        - Caryopsis
        - Achene
        - Samara
        - Nut
        - Utricle
        - Cypsela
      - Schizocarpic (splitting) Many seeded
        - Lomentum
        - Cremocarp
        - Double/compound samara
        - Regma
        - Carcerulus
    - **Succulent/ fleshy fruits** (Pericarp fleshy)
      - Drupe (endocarp Stony)
      - Berry (endocarp pulpy)
        - Superior berry
        - Inferior berry
        - Parthenocarpic berry
        - Special berry
          - Hesperidium
          - Balausta
          - Amphisarca
          - Pepo
          - Fibrous berry
      - Pome (Thalamus fleshy)
  - **Aggregate** (Etaerio fruits)
    - Etaerio of achenes
    - Etaerio of follicles
    - Etaerio of drupes
    - Etaerio fo samaras
    - Etaerio of berries
  - **Composite** (Multiple fruits)
    - Sorosis
    - Syconus

1. **Sorosis.** The composite fruit develops from either a spike or female catkin inflorescence. It is a female catkin in Mulberry (*Morus*) The whole fruit including perianth and fleshy axis (rachis) is edible. Pineapple (*Ananas camosus)* develops from intercalary sterile spike. The rhomboidal areas on outside of fruit represent position of bracteate flowers. Edible part is outer fleshy rachis (peduncle). Persistent bracts and perianth and pericarp fused together. In Jackfruit (develped from spike) the peduncle (rachis) and perianth of individual flowers become fleshy. The spines on Jackfuit represent fused stigma of carpels.

2. **Syconus** (Syconium). It develops from coenanthium or hypanthodium inflorescence. The flask-shaped or open saucer receptacle becomes fleshy and edible, *e.g., Ficus* sp (like Peepal, Fig, Banyan, *Dorstenia*). It is a pseudocarpic fruit. In *Ficus*, female flowers develop achene giving rise to a multiple fruit of achenes inside fleshy thalamus. A similar fruit is formed in *Dorstenia* where inflorescence coenanthium develops achenes on the open receptacle.

Edible parts of some common fruits and their types

I. Simple Fruits

Common / English name	*Botanical Name*	*Type*	*Edible parts*
Tamarind	*Tamarindus Indica*	Legume (lomentum)	Pericarp
Pea	*Pisum Sativum*	Legume/Pod	Seeds
Lady's finger/Okra (*Hibiscus esculentus*)	*Abelmoschus esculentus*	Capsule	Entire fruit (Pericap and seeds)
Wheat	*Triticum Aestivum*	Caryopsis	Entire fruit (endosperm and embryo)
Corn/Maize	*Zea mays*	Caryopsis	Entire fruit
Rice/Paddy	*Oryza sativa*	—do—	—do—
Cashew nut	*Anacardium occidentale*	Nut	Cotyledons and fleshy peduncle
Walnut	*Juglans regia*	Nut	Lobed convoluted oily cotyledons
Pistacia nut (Pista)	*Pistachia vera*	Nut	cotyledons
Litchi	*Litchi chinensis*	Nut	Fleshy Aril
Ground nut	*Arachis hypogea*	Lomentum	Seed
Coriander	*Coriandrum sativum*	Cremocarp	Entire fruit
Mango	*Mangifera indica*	Drupe	Fleshy Mesocarp
Water chestnut	*Trapa bispinosa*	Drupe	Seeds (cotyldeons)
Apricot (Khurmani)	*Prunus armeniaca*	Drupe	Mesocarp
Phalsa	*Grewia asiatica*	Drupe	Mesocarp
Goose berry	*Emblica officinalis*	Drupe	Fleshy Pericarp
Cherry	*Prunus avium*	Drupe	Epicarp and mesocarp
Coconut	*Cocos nucifera*	Drupe	Endosperm or entire seed
Indian Jujube (Ber)	*Zizyphus jujuba*	Drupe	Epicarp and Mesocarp
Plum (Alucha)	*Prunus domestica*	Drupe	Epicarp and Mesocarp

Almond	*Prunus amygdalus*	Drupe	Seeds
Peach (Aaru)	*Prunus persica*	Drupe	Epicarp and Mesocarp
Apple	*Pyrus malus*	Pome	Fleshy thalamus
Loquat	*Eriobotrya japonica*	Pome	Fleshy thalamus
Pear	*Pyrus communis*	Pome	Fleshy thalamus
Chilies	*Capsicum sp.*	Berry	Whole fruit and seeds
Cape gooseberry	*Physalis peruviana*	Berry	Pericarp, placentae and seeds
Tomato	*Lycopersicum esculentum*	Berry	Entire pericarp, placentae and seeds
Brinjal	*Solanum melongena*	Berry	Pericarp and placentae seeds & persistent sepals
Black berry (Jambolan)	*Syzygium jambolina*	Berry	Pericarp (Epicarp, Mesocarp, Endocarp)
Grape	*Vitis vinifera*	Berry	Pericarp and placentae
Date Palm	*Phoenix dactylifera*	Berry	Epicarp and Mesocarp
Banana	*Musa paradisica var. sapientum*	Berry	Mesocarp and Less developed endocarp
Sapodilla (Cheeku)	*Achras sapota*	Berry	Meso and endocarp
Guava	*Psidium guajava*	Berry	Pericarp with thalamus fused placentae & seeds
Betal nut	*Areca catechu*	Berry	Seeds (endosperm)
Papaw (Papaya)	*Carica papaya*	Berry	Mesocarp
Bottle gourd	*Lagenaria siceraria*	Pepo	Mesocarp, Endocarp and young seeds & placentae
Smooth gourd (Tori)	*Luffa aegyptiaca*	Pepo	Meso and endocarp, placentae and seeds
Cucumber	*Cucumis sativus*	Pepo	Mesocarp, Endocarp and yound seeds with placentae
Watermelon	*Citrullus lunatus*	Pepo	Mesocarp, Endocarp and shelled seeds
Long cucumber (Kakri)	*Cucumis melo var. utilissima*	Pepo	Thalamus and pericarp (entire fruit) and placentae, seeds
Karela (Bitter gourd)	*Momordica charantia*	Pepo	Mesocarp, Endocarp placentae and seeds
Muskmelon	*Cucumis melo*	Pepo	Mesocarp, Endocarp and Shelled seeds
Lime/Orange/Pomello	*Citrus spp.*	Hesperidium berry	Juicy glandular multicellular hair arising from endocarp
Pomegranate (Anaar)	*Punica granatum*	Balausta berry	Juicy Testa (seed coat) of seeds
Bengal quince (wood apple)	*Aegle marmelos*	Amphisarca	Inner fleshy layer of pericarp and fleshy placentae

II. Aggregate fruits

Lotus	*Nelumbo nucifera*	Etaerio of achenes	Seeds
Strawberry	*Frageria vesca*	Etaerio of achenes	Fleshy thalamus & seeds
Custard apple	*Annona squamosa*	Etaerio of berries	Inner layer of pericarp of individual berry except apices
Raspberry	*Rubus ideaus*	Etaerio of drupes	Thalamus and drupes

III. Multiple or Composite fruits

Mulberry	*Morus alba and m.nigra*	Sorosis	Succulent perianth enclosing fruits and inflorescence axis
Pine apple	*Ananas comosus*	Sorosis	Bracts, fused perianth with pericarp and outer fleshy part of peduncle (rachis)
Jack fruit (Kathal)	*Artocarpus heterophyllus*	Sorosis	Rachis (outer part of fleshy axis) bracts juicy perianth and seeds
Fig/Angeer	*Ficus carica*	Syconus	Fleshy receptacle (rachis) and seeds
Dorstenia	*Dorstenia*	Syconus	Rachis, seeds

SEED AND SEED DORMANCY

Seed is a fertilised and ripened ovule (mature integumented megasporangium) found in phanerogams (spermatophytes). It contains an inactive embryo (in suspended animation) and reserve food for its future development.

A seed has 2 parts namely *seed coat* and *kernel.* Seed coat* is protective and derived from integument/s of ovule which in turn is derived from chalaza* of ovule. In unitegmic seed, there is only one layer while in bitegmic seeds, seed coat has two layers; outer thick testa for protection (derived from outer integument) and inner thin tegmen for insulation (derived from inner integument of ovule). A small pore *called micropyle* is found on seed coat for passage of water during seed germination. *Kernal* is represented by endosperm and embryo. Endosperm may or may not be present in seeds. Embryo has an embryo axis or **tigellum** with **plumule** (or future shoot) at one end and **radicle** (or future root) at the other end. The embryo axis bears a node on which one or two cotyledons develop. Food reserve is present in thick cotyledons in endospermic or albuminous seed, *e.g.,* Castor or persistant nucellus or perisperm (perispermic seed, *e.g., Nymphaea*, Black Pepper) or hypocotyl (*e.g.,* Brazil Nut = *Bertholettia*) and **aril** (collar like outgrowth of funiculus, *e.g., Litchi*). **Caruncle** is an outgrowth of integument in the region of micropyle (*e.g.,* Castor seed). In Cotton, testa develops

* Single layered seed coat is found in Asteraceae, *Cycas*; three layered seed coat *e.g., Asphodelus*, Litchi. No seed coat in *Loranthus, Viscum, Santalum*.

* Chalaza is basal part of ovule from where integuments arise. It is most active part of the ovule.

2 types of epidermal hairs; Lint (long) and Fuzz (short). Endosperm possesses surface ridges and grooves in *Areca* (Betel Nut). It is called **ruminate** endosperm *e.g.*, Betel (Arecanut), *Passiflora*, *Antigonon*.

An angiospermic seed* represents 3 generations. (1) future sporophyte (embyro), (2) parent sporophyte (seed coat) and (3) endosperm (3x) but no gametophytic generation is found in angiospermic seeds (cf gymnospermic seeds). A seed performs three major functions in (i) (D) perennation (ii) dispersal (iii) and multiplication.

Morphology of Pea Seed (*Pisum sativum*)

Pea seed is rounded, dicot, nonendospermic seed that develops inside a pod or legume. It bears an oval scar or **hilum** (point of attachment of seed with funiculus (seed stalk). Kernel is seed minus seed coat. Below hilum is present **micropyle** while the other side has a short **raphe**. The seed is covered by seed coat with outer thick **testa** and inner thin semitransparent colourless **tegmen**. Seed coats enclose an embryo. Embryo has slightly curved **embryo axis** in between **cotyledons**. The latter are attached to embryo axis at cotyledonary node. The tip of bent end of embryo axis is **plumule** (future shoot). it is covered by a few small rudimentary leaves. The other end of embryo axis slightly projects out of cotyledons and is called **radicle** (future root). Area of the embryo axis between radicle and cotyledonary node is **hypocotyl**. The area between cotyledonary node and plumule is **epicotyl**.

Morphology of Castor Seed (Castor Bean, *Ricinus communis*)

It is a conical oblong mottled dark brown shining dicot endospermic perispermic seed which develops a regma. The seed has a flat ventral side, convex dorsal side, a broader distal end and a narrow proximal end. The latter bears **hilum** (dark scar) and **micropyle** (a small pore). Micropyle and hilum are covered by bilobed integumentary white spongy structure called **caruncle**. The middle of the flat surface bears a **raphe** or ridge. The seed is surrounded by thick, hard **testa**. Inner to it is a papery white **perisperm** (also considered to be **tegmen**). Then there is a white oily mass called **endosperm**. In the centre of endosperm is present the **embryo**. Embryo contains a short embryo axis having radicle towards micropyle, a plumule and two thin papery cotyledons.

Morphology of Maize Grain (*Zea mays*)

It is, endospermic, monocot, one seeded fruit called **caryopsis** in which testa is fused with pericarp (fruit wall). It is borne on a cob (enlarged peduncle). It is flattened and conical. The upper surface of broader end bears a **papilla** or remains of style, a depressed deltoid area indicating position of underlying embryo axis. Grain covering encloses embryo towards pointed end and upper side, and endosperm towards broader end and lower side. Actually the grain is divided into 2/3rd part as endosperm and 1/3rd part as embryo. Endosperm contains stored food, mostly as starch on innerside and fat and protein towards periphery as **horn**. The outer 1–3 celled thick region of endosperm constitutes mealy **aleurone layer** where cells contain abundant protein or aleurone grains. **The aleurone layer is diploid as it is derived from integument**. It acts as lysosome and secretes hydrolytic enzymes like α-amylase and proteases for utilization of food. Embryo has an embryo axis which bears **radicle** towards the lower end, **plumule** towards the other end and a large shield shape, terminal cotyledon or **scutellum**. The outer layer of scutellum in contact with endopserm is secretory and absorptive. It is called **epithelial layer**. Its cells secrete gibberellin into endosperm which induces diastase for solublization of food. This food is then absorbed by epithelial cells and

- Hypocotyl is the youngest tissue in plant.
- Kernel is seed minus seed coat.
- Endosperm is absent in certain seeds due to lack of growth hormones ovule represents only two generations — sporophyte and gametophyte.

given to embryo. Radicle is covered by root cap and an outer sheath called **coleorhiza.** Plumule bears a few rudimentary leaves and a protective outer sheath called **coleoptile**. The latter is capable of growth. Epiblast is remain of second cotyledon in grains of grasses.

Seed Dormancy

It is innate (internal) inhibition of germination of an otherwise viable seed even when it is placed in most favourable external conditions. It is temporary phase in which active growth of embryo/seed is temporarily suspended. **Quiescence** is a condition of the seed when it fails to germinate due to external condition required for growth like temperature, moisture. Dormancy overcomes unfavourable conditions. it also helps the seed to disperse.

Reasons of Dormancy in Seeds

1. **Impermeable Seed Coats.** *e.g.*, impermeable to water (*e.g., Chenopodium, legumes*), gases (*e.g.*, Apple, *Brassica alba*) or chemicals (*e.g., Xanthium*).
2. **Tough Seed Coats.** Which provide resistance to growth of **embryo,** *e.g., Capsella, Lepidium.*
3. **Inhibitors.** Ferulic acid present in Tamato juice does not allow seeds to germinate. Other inhibitors are ABA (most common), secondary plant products like phenolic inhibitors, coumarins. They may occur in seed coats (*Cucurbita*), endosperm (*Iris*) or embryo (*e.g., Xanthium*).
4. **Excess Salts,** in seeds of *Atriplex.*
5. **After-Ripening.** The embryo is mature but the seed requires a period for gaining the ability to germinate. During this period seeds produce nescessary growth hormones, *e.g.*, Oat, Barley, Wheat.
6. **Immature Embryo.** In *Eranthis Ginkgo* the embryo is immature at the time of seed shedding. Dormancy is the period required for embryo to develop fully.
7. **Light.** Some seeds *e.g., Lactuca*, Tobacco require light exposure before germination. Such seeds are called photoblastic seeds.

Natural Breaking of Dormancy

1. Certain small seeds regularly pass through the alimentary canals of animals when digestive enzymes make their seed coats soft and permeable.
2. Weakening of impermeable and tough seed coats by mechanical abrasions & microbial activity.
3. Destruction of inhibitors by heat, cold, light and oxidation.
4. Leaching of ihibitors and salts.
5. Development and after-ripening of embryo.
6. Development of growth hormones.

Artificial Breaking of Seed Dormancy

1. **Scarification.** (Rupturing or weakening or softening of hard seed coats) by **mechanical scarification**, (filling, chipping or machine threshing) or by **chemical Scarification**. (Weakening of seed coats by hot water, fat solvents, mineral acid, *e.g.*, H_2SO_4 to remove waxy or fatty compounds from seed coat.
2. **Impaction.** In some seeds, water and oxygen are unable to penetrate because entry is blocked by a cork like filling in the opening in the seed coat. These seeds are shaken vigorously to remove this plug, *e.g., Trigonella, Melitotus.*
3. **Pressure.** Hydraulic pressure of 2000 kg for 5–20 minutes.
4. **Chilling Treatment** in some seeds like Plum, Cherry.
5. **Counteracting Inhibitors.** Soaking seeds in KNO_3, thiourea, ethylene chlorohydrin, gibberellin.

6. **Red Light.** Red light overcomes dormancy and induces seed germination in Lettuce (*Lactuca sativa*), Tobacco and Viscum. Actually red light converts *phytochrome Pr* to Pfr which causes seed germination in such photoblastic seeds.

$$\mathrm{Pr} \underset{\substack{\text{far red} \\ \text{darkness}}}{\overset{\text{red}}{\rightleftharpoons}} \mathrm{Pfr}$$

7. **Stratification.** Dormancy of seeds due to after ripening is removed by exposing hydrated seeds in aerated, moist conditions under low temperature (0–10°C) or high temperature for weeks to months. During this period, concentration of hormones, N, P and enzymes is changed.

External Factors for Seed Germination

1. **Water.** It is essential as active cells have 75–95% of water as compared to 15% in dry seeds. Water softens seed coats, transports gases, hydrolysis reserve food and transports the same to embryo cells.

2. **Temperature.** Optimum temperature for seed germination is 15°–30°C though it can occur from near 0° C to 40°C.

3. **Oxygen.** It is required in most cases (exception Rice, *Typha*).

4. **Light.** Bean seeds and Maize grains are nonphotoblastic (uninfluenced by light in their germination). Onion, Lily and Phlox seeds are negatively photoblastic (do not germinate in light) while seeds of *Viscum*, *Lactuca* and *Lepidium* are positively photoblastic. In Pea, seed germination is hastened by light.

5. **pH.** Some seeds germinate in acidic *p*H (*e.g.*, *Potamogeton*) while a few other germinate in alkaline medium. Majority germinates at near neutral *p*H.

Internal Factors for Seed Germination

They include (i) completion of seed dormancy (ii) maturity of embryo (iii) completion of after-ripening (iv) presence of sufficient food and (v) presence of viability.

Seed Germination

A viable seed when placed, under suitable environment imbibes water through seed coat and some water through micropyle. The seed coats become soft. *Imbibition is first step in seed germination.* Embryo cells become activated and *some long-lived RNAs* form hormones and enzymes. The reserve food is mobilised. **Initially the respiration is anaerobic but later it becomes aerobic.** As food is transported to embryo cells, they begin to enlarge and divide. Radicle end grows first. It is followed by growth of either epicotyl (hypogeal germination) or hypocotyl (epigeal germination). Radicle is first to come out of seed by breaking seed coat. Finally the plumule grows.

Hypogeal Germination. It is a mode of germination in which the cotyledons and the seed remain inside the soil. It is due to more growth of epicotyle. It occurs in Pea, Gram, Rice, Maize, Date palm.

Epigeal Germination. It is a mode of seed germination in which the cotyledons and seed come out of the soil. It is due to more growth of hypocotyle. Epigeal germination occurs in Castor, Cucurbits, Bean, Mustard, Sunflower, Onion Cotton and tamarind

Germination in Maize Grain. It absorbs water through general surface as micropyle is absent making the grain covering soft. Embryo becomes active. Cells of epithelial layer secrete gibberellin that passes into aleurone layer of endosperm for forming enzymes α-amylase. The latter solubilise food in endosperm. The solubilised food is absorbed by embryo through epithelial layer of scutellum.

Radicle and coleorhiza grow. Coleorhiza pierces the grain covering but it is pierced by radicle which grows to form the primary root. *Coleorhiza* produces **seminal roots** to help in absorption of water. Later on adventitious roots are formed . Coleoptile elongates, pierces the grain covering, grows upwardly and comes out of the soil. It is green. Plumule comes out and bears leaves to make the seedling nutritionally independent. As coleoptile (a part of scutellum , *i.e.*, cotyledon) comes out of soil, germination is epigeal but as such scutellum remains inside the soil (hypogeal). **Therefore, germination in maize grain is partly hypogeal and partly epigeal otherwise it is hypogeal.**

DISPERSAL OF FRUITS AND SEEDS

Dispersal is scattering of fruits and seeds to distant places away from their parents. It is essential for avoiding competition, colonisation of new areas promoting cross pollination and production of mixed population. It enhances chances of survival. It is, however, a wasteful method as majority of seeds may not find suitable place for germination. *Plants distributed by fruits/seeds have wider range of distribution.*

Dispersal is brought about by

(i) autochory (self dispersal) by explosive mechanism.

(ii) external agencies like water, air and animals.

Autochory (Dispersal by Explosion)

It is self dispersal mechanism. The fruit bursts due to compression or release of **turgor pressure** to throw the seeds to a distance. In legumes Pea, *Abrus* the wall breaks into two valves which coil and throw the seeds. Pods of *Entada gigas* (largest pod in plant kingdom) open with a loud noise. In *Geranium*, the fruit splits up *into five one seeded cocci* which remain at the tips of hygroscopic styles. The styles coil upwardly and throw the seeds out of cocci. In *Ruellia* (Acanthaceae) the exposed seeds are thrown away with the help of **jaculators (jaculator mechanism)**. Jaculator is a curved hook at the base of seed which opens with jerk to throw seeds. In Balsam (*Impatiens*) the fleshy fruit wall has turgid cells and five lines of dehiscence. Any touch or disturbance breaks the wall into five valves which roll quickly and throw the seeds. In **Squirting Cucumber** (*Ecballium elaterium*) shows **piston mechanism of dispersal.** The fruit wall encloses a mucilaginous mass having seeds. The tip of the stalk functions as a plug. Disturbance breaks the fruit from the stalk. The mucilage containing the seeds is thrown out with a great force about 20 ft away.

Anemochory (Dispersal by Wind; Gr. *Anemos* = wind, chorein to spread)

The fruits and seeds are dispersed by high winds. The important characters shown by these plants are :

1. **Dust Seeds**. The seeds are very small, dry and light, *e.g.*, 0.004 gm in *Orchis*. Such seeds can be carried by wind to over 1000 km.

2. **Flattened Fruits**. Flattening provides large surface area that helps the fruits to remain afloat in air, *e.g., Dalbergia, Albizzia.*

3. **Winged Fruits**. The fruits bear wings for air dispersal, *e.g., Ulmus, Holoptelia, Shorea, Dodonea, Hiptage, Dipterocarpus, Dioscorea* etc.

4. **Winged Seeds**. *Tecoma, Lagerstroemia, Moringa, Cinchona, Hopea* and *Pinus, jacaranda* etc.

5. **Propellar Fruits**. The fruits are flattened and twisted to spin in air, *e.g., Dalbergia, Albizzia.*

6. **Baloon Fruits**. The fruits are inflated (baloon is formed by persistent calyx) *e.g., Cardiospermum, Colutea, Physalis.*

7. **Parachute Fruits.** The fruits of some members of Compositae often possess pappus (persistent hairy calyx) which functions as parachute for wind dispersal, *e.g.*, *Sonchus*, *Taraxacum* (Dandelion), Cotton, *Calotropis*.

8. **Plumed disseminules.** These seeds bear hair all around (*e.g.*, Cotton, *Bombax*), at one end (single coma; *e.g.*, *Calotropis*) or two ends (double coma; *e.g.*, *Alstonia*) for providing lightness. Tuft of hair is known as **coma**. The pappus of Compositae and hair of *Calotropis* are commonly hygroscopic. These plumed seeds can enclose air and behave like parachute.

9. **Hairy Styles.** The fruits of *Clematis* and *Naravelia* possess persistent hairy styles which help in floating in air.

10. **Censer Mechanism.** The small seeds are shaken out of the fruits through small openings because the latter either hang down or bear long stalks which is shaken by wind *e.g.*, Poppy, *Aristolochia*, *Argemone* (prickly Poppy), *Nigella*, *Datura*, *Antirrhinum*. The pores allow only few seeds to disperse at a time.

11. **Rolling Tumble Weeds.** The mature plants get uprooted by wind and roll along the ground, scattering seeds, *Chenopodium*, *Amaranthus*, *Carthamus*, *Salsola*, *Argemone*. *In Salsola*, branches of the mature plant are incurved and main stem breaks down and the plant with seeds roll miles away as balls through wind.

Hydrochory (Dispersal by water; Gr. *Hydro* = water, *chorein* = to spread)

Water helps in dispersal of fruits and seeds of plants which are either aquatic or grow along water banks.

(i) The seeds of *Polygonum* can be held over the surface of water for dispersal.

(ii) Seeds and fruits possess air cavities to keep them afloat on water, *e.g.*, spongy seed coat of Water lily (Nymphaea), spongy thalamus (torus) of Lotus (*Nelumbo*), fibrous spongy mesocarp of Coconut and double coconut, betel nut air cavity in fruit of *Herietiera*, air cavity in seed of *Mucuna gigantia* and inside the embryo in *Entada scandens*. Aril in the seeds of water lily helps seeds to float in water by giving buoyancy.

Zoochory (Dispersal by Animals)

It is the most advantageous and specialised of all types of dispersal. It is either forced zoochory or compensated zoochory.

Forced Zoochory. Here animals are forced to carry seeds/fruits, *e.g.*, (i) Fruit and seeds falling on muddy banks are carried away by visiting animals. They fall down when the mud dries up. (ii) The fruit surface possesses sticky glands for attaching to the body of animals, *e.g.*, *Plumbago*, *Boerhaavia*, *Cleome viscosa*, *Banyan*, or possess hooks, spines, barbs, awns, etc to get attached to body of grazing animals, *e.g.*, *Martynia* (Tiger's Claw bearing two spiny hooks), *Aristida* (Spear Grass), *Medicago*, *Tribulus* (Gokhru) *Pupalia*, *Achyranthes*, *Xanthium*, (Cocklebur),

Compensated Zoochory. Either the seeds are very small and capable of passing unharmed through digestive tract of birds and animals (*e.g.*, Mulberry, Peepal, Guava, Banyan, Tomato) or the seeds are large and thrown away, *e.g.*, Apricot, Mango or sticky so that they stick to the beaks of birds and seeds are thrown away by rubbing of beaks, *e.g.*, *Viscum*, *Cardia*, *Loranthus* or Edible fruits have bitter taste in the unripe state. They develop bright colour and sweet pulp at maturity to attract animals like parrot. The seed of *Trillium* bear oily appendages which ants eat and discard seeds. Maize, Cabbage, Cauliflower, *Cinchona* , Chillies, Tobacco, Tea are dispersed by man. Seeds of *Lantana*, *Argemone*, *Parthenium* are dispersed alongwith useful plants.

DEFENCE MECHANISMS IN PLANTS

Plants develop structures like thorns, spines, prickles, hairs, geophilous or mimicry habits to protect themselves from exploiters/enemies/grazing, browsing and trampling. The various defensive devices in plants are;

1. **Pointed structures.** (a) *Stem Thorns* (Stem modifications are deep seated and are found in lemon, pomegranate and Duranta. (b) Sharp pointed spines at the leaf ends in Pineapple, Yucca, Agave and Date palm; Leafy spines in *Opuntia* and other cacti. (c) Prickles are superficial in rose and silk cotton tree (Bombax), *Argemone*.

2. **Hairs**. Glandular unicellular stinging hairs with sharp and siliceous tip containing poisonous sap occur on all parts of the plant in nettles like *Laportea* and *Urtica*, dioica (Bichchu Booti). The tip breaks on being rubbed by animal and the hairs pierce the skin and cause irritation.

3. **Coverings.** (a) *Glandular hair* with sticky substances are found in *Jatropha, Boerhaavia* and tobacco. As a result the plant parts stick to the face of the browsing animal and cause irritation. (b) Dense coating of hairs or stiff hair on cud weed (*Gnaphalium*) and many Cucurbits repel animals.

4. **Repulsive Substances.** Some plants secrete poisonous, and irritating or nontasty substances in the form of *latex* (*e.g., Ficus, Nerium, Thavetia, Euphorbia, Calotropis),* alkaloids (*e.g.*, Poppy, *Datura* and tabacco) and irritating raphides and other crystals in *Colocasia* and other aroids. The plants of mint (*Mentha*) tulsi (*Ocimum*), Neem, Karela have bitter taste.

5. **Geophilous** habit (underground nature) in Ginger, turmeric, colocasia, onion, tubers protect them from enemies.

6. Some plants like Peepal, Mango, Jambolana, Guava and Litchi harbour ants (*Myrmecophily*) which save the plant from other animals.

7. **Mimicry** is habit of imitating shape, size, colour of other animals/plants, which are disliked by enemies. Aroids (like *Cladium*, Arisaema*)* and *Sansevieria* resemble spotted snakes so that plant eating animals do not cause much harm. The spathe of infloresence of cobra plant, *Arisaema speciosa* found in forests of Shillong and Darjeeling resemble the hood of a cobra.

READ AND DIGEST

- True touch me not plants are *Ecballium elaterium*, a cucurbit – ripe fruits burst on touch. Balsam (*Impatiens balsamina*) – ripe fruits burst on touch.
- **Sarracenia.** An insectivorous plant in which pitcher is sessile & largest but otherwise similar to *Nepenthes.*
- **Dischidia.** The pitcher is without lid and is used only for-storing rain water with some humus rich mud. It is not insectivorous.
- **Aldrovanda** (Water Flea Trap). Rootless free floating aquatic with leaves similar to *Dionaea* in trapping small animals.

ROOT

- **Plantless root.** In plants like *Arceuthobium, Rafflesia, Sapria, Podostemon, Monotropa* shoot develops for flowering otherwise roots from main part of the plant.
- **Pseudoepiphyte** : These plants have normal root system but are capable of climbing and become unconnected with soil like epiphytes *e.g., Monstera, Scindapsus*
- *Nest roots* are adventitious roots in pitcher (nest) of *Dischidia* (a non insectivorous plant) for absorption of water and minerals from the humus rich soil collected in these nests.
- Roots arising from callus in tissue culture are adventitious.
- *Seminal roots* are thread like lateral roots arise from coleorhiza and behave as primary root in monocots.
- Rootless Plants– *Utricularia, Wolffia, Epipogium, Balanophora, Cuscuta, Ceratophyllum, Myriophyllum* etc.

• The cells of root cap are rich in Golgi bodies and secrete mucilage.

• Root cap grows continuously and a broken root cap is replaced by new one **but toot pockets are not replaceable**.

• Mangrooves are halophytes with prop roots and or Pneumatophores. *Rhizophora* is without pneumatophores. These pneumatophores are *organ suigeneris* (unknown origin).

• Life of root hairs is hardly one week. During transplantation, root hairs are shed and therefore, plant remains wilted for sometime till the formation of new root hairs.

• *Cuscuta reflexa*: It is a total stem parasite, bears haustorial roots, its seed has no cotyledon, it makes connection with xylem and phloem of host and it behaves as short day plant if its host is a SDP and behave as long day plant if host is LDP.

• Roots of sweet Potato (Sakarkandi), Asparagus, Radish, Carrot, Turnip, beet are edible. Roots of sugar beet are source of Sugar. Roots of *Vinca rosea* and *Hemidesmus* are medicinal. Roots of *Rauwolfia* are source of resperpine for treating blood pressure. Roots of *Ferula asafoetida* (Heeng) secrete oleoresin, source of Heeng.

STEM

• **Thorns, spines and prickles**. Thorns are modified stem structures while spines are modified leaves or leaf parts. Both of them have cortex and vascular supply. Prickles are epidermal outgrowths or emergences which do not have vascular supply. Prickles are associated with stem.

• **Pseudostem/False Stem**. A trunk formed by aggregation of leaf bases as in Banana.

• **Scape** is a hollow, unbranched, leafless aerial long shoot that bears flowers at apex. It actually develops from terminal bud in Ariods, Banana, Onion and some other monocots.

• **Branched Stem** — (a) *Excurrent*. The trunk forms lateral branches in acropetal manner giving cone like appearance (pyramidal) *e.g., Pinus, Ashok, Casuarina*. (b) *Deliquescent or decurrent*. The trunk disappears after some distance and branches spread in all directions giving a dome like appearance *e.g.*, Banyan tree.

• **Pseudobulb**. A thickened part of stem (one or a few internodes) in orchids like *Bulbophyllum* and some other plants for storing water and reserves.

• **Tuberous Stem**. *Bulbophyllum* (only first internode), Knol–Kohl (whole stem).

• **Acaulescent**, a plant with the reduced stem, *e.g, Onion*.

• **Largest vegetative and apical Bud.** Cabbage. It stores food and is edible.

• Arborescent habit is Palm like appearance *e.g.*, caudex of *Cycas*.

• ***Ulex***. Possesses both stem thorns as well as leaf spines.

• **Liana.** Woody climber or twiner *e.g., Bougainvillea, Gnetum, Yucca*.

• Corm of *Amorphophallus campanulatus* (Elephants foot, Zaminkand) is largest corm of one internode. Alkaloid in *Amorphophallus* (zaminkand) allergic to our tongue is amorphine.

• Banana (*Musa paradisiaca)* is called *Herbaceous tree*. Bamboo is tallest grass of Gramineae (grass family) and called *Tree Grass*. Bamboo of commerce is culm.

• The anti cancerous substance in garlic is gernium.

• The odour in onion and garlic is due to allyl sulphonate, called allocinin and Eye tearing is due to a volatile thiosulphonates. Onion is edible underground bud.

• Stem is quadangular in *Ocimums :* triangular in Cyperus, ribbed in cucurbits and flat in Cactus.

• **Gloriosa** is a climber with **rhizome**.

• Rhizome is diageotropic.

LEAF

• **Heterophylly**. Presence of 2 types of leaves in the same plant. It is common in aquatic plant growing in running water and some land plants like *Artocarpus* (Jack fruit), *Hemiphragma* and *Ficus heterophylla*.

Hetrophylly is of 3 types : (a) *Environmental or adaptative Heterophylly* : difference is due to environmenta actors like soil, temperature, humidity and air currents, *Limnophila, Sagittaria*.

(b) *Habitual heterophylly* : It is development of foliage leaves of different size and shape *e.g.*, Jack frui (Artrocarpus).

(c) *Developmental heterophylly* : It is the change from juvenile to mature foliage in the development of individual *e.g., Eucalyptus*.

• **Leaf colouration** : Young leaves, of certain plants are red due to anthocyanin in cell sap. At the time of leaf fall or in autumn, leaves become brown (*autumn colouration*) and due to tannin deposition and loss of chlorophyll and carotenoids become apparent.

• **Types of Leaf Margins**

Type of Margin	Details	Examples
1. Entire	Even, Smooth	Banana, Grasses, Banyan, Mango
2. Wavy/Repand	Uneven having crests and depression like a wave	*Polyalthia*
3. Serrate	Incised like a saw	Rose, *Hibiscus rosa sinensis*
4. Biserrate	Having teeth which themselves are incised like a saw	Elm
5. Dentate	Teeth making an angle of 90° with the margin	Water lilly
6. Crenate	Teeth rounded	*Bryophyllum, Hydrocotyle*
7. Spiny	Spiny margin	*Argemone, Ananas*
8. Lobed	Incised, so that leaf is divided into small lobes	Mustard, *Raphanus sativus*

• **Types of Apices of Lamina**

Type of Apex	Details	Examples
1. Acute	Pointed; both the margins of lamina meet to make an angle of less than 90°	Mango
2. Acuminate	Suddenly tapers forming tail like structure	*Hibiscus rosa-sinensis*
3. Obtuse	Broad, round, blunt, both margins of lamina making an angle of more than 90°	*Ficus religiosa*
4. Mucronate	Broad, round, having a small projection	Banyan
5. Spiny/Cuspidate	Pointed, hair, sharp like spine	*Vinca rosea, Ixora*
6. Tendrillar	Modified into tendril	Date palm, Ananas
7. Cirrhose	Ends in a small, thin, fibre-like structure	*Gloriosa*
8. Truncate	Sharply cut	Banana
9. Retuse	Notch at the apex	*Paris polyphylla*
10. Emarginate	Deep notch at the apex dividing the leaf into two lobes	*Pistia*
		Oxalis, Bauhinia

• **Different Shapes of Lamina**

Shapes	Details	Examples
1. Linear	Long, narrow, having parallel margins	Wheat, rice, grass
2. Lanceolate	Pear shaped (lower side *i.e.*, below midpoint, thick; pointed at ends).	Bomboo, *Nerium, Polyalthia*
3. Oblong	Rectangular, long, broad & with a round apex	Banana
4. Ovate	Egg-shaped (base wider than apex)	Banyan
5. Cordate	Heart-shaped	Betel, *Tinospora*
6. Sagittate	Arrow-shaped	*Arum, Sagittaria*
7. Hastate	Arrow shaped but both lower lobes outwardly directed	*Ipomoea*
8. Reniform	Kidney-shaped	*Hydrocotyle*
9. Lunate	Semi-circular	*Passiflora*
10. Obovate	Like inverted egg	*Prunus amygdalus, Walnut*
11. Obcordate	Like inverted heart	*Oxalis, Bauhinia*
12. Spathulate	Like a spatula	*Calandula, Drosera*
13. Cuneate	Like hood of a snake	*Pistila*
14. Orbicular	Circular-petiole attached below the lamina near its centre	Lily, *Nasturtium, Lotus*
15. Elliptical	Oval but width slightly lesser than length	Guava

• Trifoliate type of palmate compound leaves are most common type of compound leaves. These are common in members of *Papilionaceae* family.

• **Petiolule.** Stalk of leaflet.

• Dicot leaf is dorsiventral and horizontal in position. Monocot leaf is isobilateral and vertical in position.

• Belt's corpuscles are small protein rich glands at the tips of leaflets in *Acacia sphaerocephala* (a South American plant). They secrete edible material for foracious ants. These ants take shelter (in hollow spiny stipules) and inturn protect plant from caterpillars and leaf cutting ants. This is *proto-cooperation* type of symbiosis. Ants also do pollination (myrmecophily).

• CTC (cutting, tearing and curling) tea leaves are rich in iron because they are cured in iron pans. CTC tea is balck fermented tea that India produces.

• Plant with single leaf. *Monophyllea*.

• Plant with two leaves only *Welwitschia* (a gymnosperm).

• *Anisophily*– Presence of 2 types of leaves on same node of the plant *e.g.*, *Boerhaavia*.

In florescence

• **Families named** after inflorescence : Umbelliferae (umbel inflorescence) and Amentiferae (Amentum or catkin inflorescence)

• **Inflorescence called flowers** in Cauliflower (compound corymb), Sunflower (capitulum). *Euphorbia* (cyathium).

• **Edible inflorescence:** Undeveloped compound corymb of Cauliflower, (*Brassica oleracea var. botrytis*), catkin in Mulberry (*Morus alba*); Hypanthodium in Fig (*Ficus*); Spadix in female maize (*Zeamays*).

• Fruit like inflorescence — Hypanthodium.

• Longest inflorescence: *Agave* (12 m). *Amorphophalus* (5.5 m). *Puya raimondii* (10 metres).

• When a dichasial cyme ends into a monochasial *cyme, it is called cincinus e.g.*, Dianthus (Pink flower).

• in *Mimosa, Acacia, Albizzia*, the inflorescence is capitate/spikate head/ **globose head** which resembles to capitulum (racemose head) in having centripetally flowers but the peduncle is suppressed and not flattened as in racemose head.

• **Cauliflory**. It is a condition of developing flowers from dormant axillary buds on old stem. It is common in tropical trees *e.g., Ficus* (Banyan, Peepal, Fig), *Artocarpus* (Jack fruit).

• Cob of maize is enlarged peduncle.

• Scape is leafless flowering shoot (Peduncle) developing from underground bulb, *e.g.*, onion.

• **Placentation**. 1. **Marginal** Ovary is mostly monocarpellary unilocular bearing a single longitudinal placenta in the region of ventral suture, where two margins of carpel join *e.g., Pistum sativum, Lathyrus, Acacia.*

• **Parietal**. Ovary is bi to multicarpellary but unilocular, *e.g.*, Mustard, *Cucurbita*.

• **Axile**. Ovary is syncarpous, bi to multicarpellary, bi-to multilocular. The placentae bearing ovules borne on central axile column where margins of all carpels fuse, *e.g., Petunia*, Shoe flower, *Allium*.

• **Free Central.** Ovary is multicarpellary unilocular. Ovules are borne on a central axile column which is not connected to ovary wall by any septum, *e.g.*, Silene, Dianthus.

• **Basal**. Ovary is bi- multicarpellary but unilocular. A single ovule is borne at the base of ovary, *e.g., Ranunculus*, Sunflower.

• **Superficial**. Ovary is multicarpellary, multilocular. The placentae bearing ovules are borne all over the inner surface of the ovary including the septa in case of multilocular condition, *e.g., Butomus* (unilocular), *Nymphaea* (multilocular) *e.g., Argemone.*

• **Relative Position of Floral Organs**

• **Hypogynous Flower** (Hypogyny). Thalamus is conical or convex with gynaecium at top and other parts below it, ovary is superior and other parts inferior, *e.g.*, Mustard, *Petunia*, Shoe flower (China rose).

• **Perigynous Flower** (Perigyny). Thalamus grows marginally to produce floral cup called **hypanthium**. Perigynous thalamus is of three types. (i) **Disc-shaped.** Flat thalamus, *e.g.*, Pea, (ii) **Cup-shaped.** Thalamus is like a saucer or cup with gynaecium at the bottom and other floral organs borne at the ring, *e.g., Plum, Peach, Prunus.* (iii) **Flask-shaped.** Thalamus is like a hollow flask, *e.g.*, Rose. In all cases, gynaecium is superior and other floral organs inferior. Thalamus does not fuse with ovary.

• **Epigynous Flower**. Thalamus is hollowed out and fused with ovary. Other floral organs appear at the top of ovary. Gynaecium is inferior while other parts are superior, *e.g.*, Sunflower, Carrot, Guava, Apple, Cucumber etc.

• Study of flowers is called anthology.

• **Homology in sex organs between Gymnosperms and Angiosperms**

Angiosperm		*Gymnosperm*	*Angiosperm*		*Gymnosperm*
1. Flower	=	Cone/Strobilus	6. Ovary/carpel	=	Megasporophyll
2. Stamen	=	Microsporophyll	7. Ovule/Nucellus	=	Megasporangium
3. Pollen sacs	=	Microsporangia	8. Embryo sac	=	Female gametophyte
4. Pollen grains	=	Microspores	9. Egg apparatus	=	Archegonium
5. Pollen tube	=	Male gametophyte	10. Egg (Oosphere)	=	Female gamete

• **Stylopodium.** Swollen base of style forming a pad like structure in umbelliferae.

• **Bracts.** Special small leaf-like structure in the axil of which a flower develops. Types (i) **Leafy** (foliaceous) green Bracts, *e.g.*, *Adhatoda*, *Acalypha* (ii) **Petaloid** Coloured, *e.g.*, *Bougainvillea*, *Poinsettia* (iii) **Involucre**. Forming one or more whorls at the base of a condensed inflorescence. (iv) **Epicalyx** are bracteoles below the calyx *e.g.* Malvaceae. (v) **Spathe**. Large bract, enclosing infloresence (spadix). (vi) **Cupule**. Hardy woody bracts *e.g.* oak. (vii) **Glumes**. Small dry empty bracts over the spikelet

• **Longest and hairy stigma** and **style**. Maize. Bifid stigma in Sunflower. Feathery stigma – cereals. Funnel shaped stigma – *Crocus*. Synangia – fusion of ovaries of two adjacent flowers, *e.g.*, 2 fused banana. Persistant wheel like stigma – Poppy (*Papaver*). Carpel is like a rolled leaf in *Degenaria*. Style and stigma of *Crocus* are edible and source of kesar (saffron). Persistent syle in *Clematis Narvelia*, Maize. In *Clematis*, styles persist after fertilization and become feathery. **Spines** on Jackfruit are formed by stigma.

• Cleistogamous flowers never open. Chasmogamous flower open at maturity. Stamens are branched in *Ricinus* (Castor bean).

• Pollen grains of *Parthenium hysterophorus* (congress grass) are allergenic to cause hay fever.

• *Coronary Corona*: found in *Calotropis*. *Staminal Corona* in *Nerium*

• **Cauliflory** : It is production of flowers on old stem from dormant buds. It is common in tropical forests, *e.g.*, *Ficus*, Mango, *Cassia*, *Artocarpus*. Hypanthodium inflorescence arises from such dormant buds on old stem.

• In monothecous stamen, connective is absent.

• **Monoandrous** : A flower with one stamen only, *e.g.*, *Euphorbia*.

• **Lodicules** are modified tepals (Perianth)

• Calyx and corolla together called chlamydae.

• In **Aconitum**, sepals are like monk's hood.

Families of Angiosperms

• Minimum number of chromosomes in Angiosperms 2n = 4 in *Haplopappus gracilis*. Maximum number is 2n = 266 in *Poa litorosa*

• According to ICBN (International Code of Botanical Nomenclature), name of the family is a plural adjective (*e.g.*, Ranunculaceae is well represented in India and is formed by adding the suffix — aceae to the valid name of an included genus. The names of following 8 families have accordingly been changed.

Old name	New name	Old name	New name
Palmae	Arecaceae	Gramineae	Poaceae
Cruciferae	Brassicaceae	Leguminosae	Fabaceae
Guttiferae	Clusiaceae	Umbelliferae	Apiaceae
Labiatae	Lamiaceae	Compositae	Asteraceae

• *Mother axis* : The shoot on which the flower is bome is called mother axis.

• *Chorisis :* It is increase in number of members of a single whorl due to splitting *e.g.*, doubling of flowers in Double china rose, double poppy.

• Basal placentation is most advanced while superficial placentation is most primitive.

• Hemi/Spirocyclic flower : A flower in which some of the floral parts are in circles and some are spirally arranged *e.g.*, Ranunculaceae in which sepals and petals are found in circles (whorl) and stamens and carpels are arranged spirally.

• Most primitive family is Ranunculaceae and most advanced is Compositae

• Proteins of cereals and millets are deficient in lysine mainly as well as tryptophan and threonine while of pulses, it is deficient in sulphur containing amino acids like cysteine methonine.

• Maximum timber is provided by Mimosaceae; **fodder** and **protein** by Papilinaceae; **forage grasslands** by Gramineae; vegetables by Solanaceae; **fruits** by Rutaceae and **flowers** by Compositae.

Fruit

• **National Fruit of India.** Mango/*Mangifera Indica*.

• **Largest Fruit/Largest seed.** *Lodoicea Maldivica*/Double Coconut. Smallest fruit is of *Wolffia*.

• Bitter taste of some cucurbits is due to tetracyclic triterpenes.

• Browning of cut Apple, Guava, Peach is due to oxidation of flavones and tannins/polyphenols. Iron of knife reacts with flavones and tannins to form green purple compound.

• Stylopodium is swollen base of the style in cremocarpic fruits.

• No part of fruit is edible in pulses, Apple, Cashewnut, Walnut, Pista, Waterchestnut, Areca Nut, Coconut,Litchi, Almond, Jack fruit, Fig, Lotus, Pomegranate, Mulberry, Pear, Pineapple, Raspberry, Starwberry.

• In pineapple and Jack fruit spines on the tough rind represent the fused **stigmas of the carpels.**

• All multiple fruits are false (Pseudocarpic) fruits.

• **Parthenocarpy**. In many cases, fruit is formed without fertilization.

• Banana is pseudocarpic parthenocarpic inferior berry.

• **True Nuts** are one seeded, simple, dry, achenial fruits in which pericarp is hard/leathery, *e.g.*, Oak (acron) nut, walnut (*Juglans, Akhrot*), chestnut, cashewnut (*Anacardium*), Kaju, Pista nut (*Pistachia*), Litchi.

False Nuts. Arecanut/Betelnut (a berry); Peanut, Groundnut (a lomentum pod) ; Double coconut and Coconut (a drupe) ; pinenut (seed of *Pinus*) ; water/chest nut (*Trapa*, Shingara — a drupe) ; soapnut (*Sapindus* ; ritha a seed)

• In berries mesocarp is thick and fleshy and endocarp is pulpy. But in Arecanut (betel nut, supari) no part of fruit is edible. It is endosperm of seed that makes edible part.

• Brinjal is a false fruit.
• Ground nut/pea nut is geocarpic fruit.
• Guava is cheapest source of vitamin C.
• Citrus fruits are rich in Vitamin C and Ca^{++}.
• Dried raisins, dates and figs are rich in iron.
• Grapes are sour due to tartaric acid.
• Fruits are good source of Na, K, Mg vitamin C and A.

• **False berries**. These are not true berries, *e.g.*, Goose berry of *Emblica* (Amla), a drupe ; strawberry (etaerio of achenes) ; Raspberry (etaerio of drupes ; Mulberry (sorosis)

• **Caruncle** is a spongy bilobed outgrowth of outer integument at micropylar end that helps in absorption of water and myrmecophily *e.g.,* Castor seed.

• **Perisperm** is unused/remnant of nucellus in some seeds *e.g.,* Coffee, Black pepper.

True berries:- Cape goose berry (*Physalis*).

• Smallest seed is of *Orchis* (wt 0.004 mg) and 1 gram contains 20 lakh seeds

• **Recalcirant Seeds**. The seeds get killed on reduction of moisture and exposure to low temperature, *e.g.*, Tea, Jack Fruit, Coconut.

• **Orthodox Seeds**. The seeds which can be stored for long as they can tolerate reduction in moisture content (upto 5%) exposure to low temperature and anaerobic conditions, *e.g.,* legumes, cereals.

• *Abronia*, *Corydalis* and *Trapa* have dicot seeds but have only one cotyledon. *Loranthus* seeds are polycotyledonous with 2-6 cotyledons.

• In Dicot seed, cotyledon is lateral and plumule is terminal. In Monocot seed cotyledon is terminal and plumule is lateral in position.

• Monocot seeds are mostly endospermic (cereals, palms) but some are nonendospermic, *e.g., Orchids, Sagittaria.*

• Polishing of rice causes loss of embryo and aleurone layer and thereby decreases nutritional value of grain.

• Aril of *Myristica* (Nutmeg) is source of *Javitri* used as spice.

• **Aril**. It is a post fertilized fleshy collar like covering at micropylar end on the seed that arises as an outgrowth of the funiculus and acts as third integument of ovule, *e.g.*, Litchi, Nutmeg (*Myristica*), Yew, Igna and Waterlily, In *Litchi* it is edible.

• **Caruncle** is bilobed spongy outgrowth of the outer integument at micropylar end/hilum of seed, *e.g.*, Castor bean (*Ricinus*). It absorbs water during germination of seed.

• **Endospermic seeds–** Endosperm persists in seeds and stores food, *e.g.*, Castor and cereals like Maize, Wheat, Rice, Rubber, Cotton, Coconut, Banana, Date Palm, Arecanut, Cucurbits, Waterlily (*Nymphaea*) Cardamom, *Phytelephas*, Papaya.

• **Nonendospermic seeds–** Endosperm is used up by growing embryo and, therefore, not present in mature seeds, *e.g.*, Legumes (Gram, Pea, Bean), Groundnut, Soybean, *Sagittaria*, Orchids, *Almond, Sunflower, Cucurbits, Vallisneria*, rape/mustard seed. Here food is stored in cotyledons and hence coyledons are thick.

• **Perispermic seeds.** Perisperm is unused (remnant part) nucellus which persists in seeds alongwith endosperm. It lies outside embryo sac and is eaten as food, *e.g.*, Mace (Nutmeg), Cardamom (*Amomum*), Black Pepper, Coffee, *Pinus*, Castor, *Nymphaea* (Water lilly).

- Test of Viability of seed : It is tested by treating embryo of seeds with TPC. In the viable seeds the embryo shows respiration. It reduces colourless solution of TPC to pink in 0.1% TPC (triphenyl tetrazolium chloride) solution within 30 minutes.
- **Viability of seeds.** Ability of seed to retain power of germination over a period of time is called viability. It is maximum in Lotus (*Nelumbo nucifera*) *i.e.*, 400-2000 years, few weeks in *Oxalis* and 100 yrs in *Trifolium*.
- **Vivipary** is germination of seeds within fruit (*in situ*) while attached to the parent plant, *e.g.*, mangrooves (*Rhizophora, Sonneratia*). Vivipary is also found in Coconut, Bryophyllum, Agave, Papaya, Sechium.
- Endosperm is oily in Castor bean, starchy in cereals/maize, cellulosic in Areca nut, *Phytelephas* (vegetable ivory), hemicellulosic in Date palm and coffee. The endosperm of *Phytelephas* is very hard and used to make umbrella handles, button and billiard *ball*.
- In Sunflower, cotyledons are oily.
- *Calotropis* is insect pollinated but dispersed by wind. Its seeds are plumed (hairy). It has pollinia containing anthers to be carried by insects.
- *Pappus* are modified persistent hairy sepals in some members of compositae like *Sonchus, Tridax, Taraxacum, Dandelion)*. They help in wind dispersal by acting as parachute.
- In *Rafflesia*, dispersal of seeds is by elephant.

MULTIPLE CHOICE QUESTIONS

1. Region of root from base to root tip in a tap root are
   (1) Maturation zone (MZ) – Cell division zone (CDZ) – Elongation zone (EZ)
   (2) MZ – EZ – CDZ
   (3) CDZ – EZ – MZ
   (4) EZ – CDZ – MZ
2. Tap (primary) root is descending axis that develops from
   (1) radicle (2) hypocotyl
   (3) epicotyl (4) radical
3. Adventitious roots are
   (1) those arising from any part of plant other than radicle
   (2) found only in monocots
   (3) found in bryophytes also
   (4) all of the above
4. Root pockets act as balancers and found in
   (1) hygrophytes
   (2) free floating hydrophytes
   (3) fixed floating hydrophytes
   (4) all of the above
5. The graviperception (geotropic response) of root is due to starch grains (statoliths) in
   (1) cells of root cap
   (2) cells of root hairs
   (3) cells in root apex
   (4) cells in growing point
6. Root hairs lost during transplantation but re-appear within a week. These root hairs are found in
   (1) zone of division
   (2) zone of elongation
   (3) zone of maturation
   (4) all zones
7. Secondary growth and lateral roots are found in which part of root ?
   (1) Calyptra region (2) Root hair zone
   (3) Zone of mature cells
   (4) Zone of elongation
8. Reproductive roots taking part in reproduction are found in
   (1) *Dalbergia* (Shisham)
   (2) *Dahlia*
   (3) Sweet potato (*Ipomoea*)
   (4) All correct.
9. Which plant(s) bears hygroscopic (epiphytic) roots ?
   (1) *Vanda* (2) *Crocus*
   (3) Trapa (4) All of the above
10. Floating white, breathing spongy roots are found in which of the following fresh water plants ?
    (1) *Jussiaea* (2) *Trapa*
    (3) *Avicennia* (4) *Salvinia*
11. Roots help in clinging and climbing in
    (1) *Pothos* and *Tecoma*
    (2) *Asparagus*
    (3) *Pandanus*
    (4) All are correct.
12. Rootless angiosperms are
    (1) *Podostemum* & *Pothos*
    (2) *Ludwigia*
    (3) *Wolffia* and *Utricularia*
    (4) All are correct.
13. Pneumatophores are common in halophytes of saline swampy soil of sea shores for
    (1) respiration (2) guttation
    (3) both (1) & (2) (4) Vivipary
14. In maize and sugarcane stem, stilt roots arise from
    (1) lower internodes (2) lower nodes
    (3) any node (4) any internode
15. Haustoria help in survival of
    (1) epiphytes (2) saprophytes
    (3) parasites (4) all of these
16. In Sweet Potato (*Ipomoea batatas*) food is stored in
    (1) tap tuberous roots
    (2) adventitious tuberous roots
    (3) stem
    (4) underground stem
17. Suppose a plant has tuberous roots and rhizomes both as underground structures. How can you distinguish a root from rhizome ?
    (1) Root has no scale leaves and nodes and internodes.
    (2) Root is thicker and rhizome is thinner
    (3) Root remains non-green and rhizome becomes green on exposure to sunlight.
    (4) Root bear root hairs and rhizome does not bear any hairs

18. Tap roots are common in
(1) monocots (2) dicots
(3) weeds (4) grasses

19. Which one is a fleshy root ?
(1) *Ficus benghalensis* and *Solanum tuberosum*
(2) *Raphanus sativus* and *Daucus carota*
(3) *Colocasia* and *Allium*
(4) *Chrysanthemum* and *Tecoma*

20. Pneumatophores are found in
(1) Tecoma & Ivy
(2) *Avicennia, Sonneratia*
(3) Pandanus
(4) All are correct

21. The adventitious, mechanical, freely, vertically hanging downward roots from stem of Banyan tree are called
(1) prop roots (2) stilt roots
(3) epiphytic roots (4) all correct

*22. A tree growing in India Botanical Garden, Sibpur (Howrah, Calcutta) with age over 200 years, circumference 404 metres, Prop roots 1600 and whose main stem has decayed is
(1) *Ficus benghalensis*
(2) *Ficus religiosa*
(3) *Eucalyptus regnans*
(4) No such tree exists

23. Velamen in Orchids *Vanda*/epiphytes is a specialised epidermis that helps in
(1) guttation
(2) absorption of water from soil
(3) absorption of moisture from air
(4) clinging the weak plant

24. Choose the correct statement about haustorial (Parasitic) roots of *Cuscuta*.
(1) These roots develop contact with xylem of host.
(2) These develop contact with xylem and phloem of host.
(3) These develop contact with phloem of host to get food.
(4) These develop contact with pericycle and lateral roots of host

25. Root hairs absent in hydrophytes because
(1) they do not absorb salts
(2) they absorb water through body surface
(3) absorption occur by leaves
(4) surface area of plant is high and roots are very large

26. An unbranched trunk with crown of leaves at apex as in Palms is called
(1) culm (2) caudex
(3) excurrent (4) deliquescent

27. A stem with jointed stem is called culm. It has distinct nodes and internodes. It is a characteristic of
(1) palms (2) bamboo
(3) *Pinus* (4) all correct.

28. A bud is
(1) embryonic shoot
(2) condensed embryonic root
(3) a condensed branch
(4) biological enigma

29. The underground modification of stem is basically for
(1) respiration (2) perennation
(3) vegetative reproduction
(4) anchorage

30. An underground stem without adventitious roots is
(1) Potato (2) Onion
(3) Colocacia (4) All correct.

31. The eyes of potato are nodes. These eyes in potato contain
(1) buds (2) roots
(3) seeds (4) all correct

32. Which is not a rhizome ?
(1) *Colocasia* (2) Lotus
(3) Ginger (4) Turmeric

33. In potato tubers, reserve food is starch. It is stachyose in *Stachys* (Chinese artichoke) tubers. In Jerusalem artichoke (*Helianthus tuberosus*), the reserve food is in the form of fan shaped crystals composed of
(1) starch (2) insulin
(3) callose (4) inulin

34. Bulb of *Allium cepa* (onion) is
(1) underground modified bud with reduced discoid stem and without adventitious roots
(2) underground shoot with reduced stem and fleshy leaves
(3) both (1) and (2) correct
(4) underground root

*22. Bodhi tree of Gaya is about 2000 years old. It is called **Tree of Enlightenment** and is *Ficus religiosa* (Peepal).

35. A bulb without tunic and loosely arranged scale leaves is called scaly or imbricated naked bulb. It is found in
(1) onion (2) garlic
(3) lilies (4) all correct.

36. A disc like reduced stem is found in
(1) Ginger (2) Canna
(3) Onion (4) *Crocus*

37. In Garlic (*Allium sativum*) each fleshy scale represents a bud called bulblet or clove. It is a bud because
(1) it has its own tunic
(2) it arises in concentric rings
(3) it has a growing point & immature leaves
(4) all correct

38. A nongreen stem branch that grows obliquely or sometimes grows horizontally inside the soil and then comes out of the soil as a branch is called
(1) stolon (2) sucker
(3) offset (4) rhizome

39. A thick fleshy underground horizontal main stem is
(1) corm (2) tuber
(3) sucker (4) rhizome

40. Stem of *Crocus* (Saffron) is
(1) rhizome (2) corm
(3) root (4) bulb

41. A vertically growing thick usually unbranched underground stem with more diameter than length is
(1) sucker (2) straggling
(3) corm (4) rootstock

42. The buds which arise at places other than nodes are called
(1) accessory buds (2) lateral buds
(3) adventitious buds (4) floral buds

43. Largest as well as apical and edible bud is of
(1) cabbage (2) cauliflower
(3) onion (4) agave

44. What is the name of that fleshy bud which takes part in vegetative propagation ?
(1) Apical bud (2) Bulbil
(3) Accessory (4) Floral buds

45. The fleshy buds helping in perennation in hydrophytes are called
(1) bulbils (2) turions
(3) corms (4) bulbs

46. Thorns differ from prickles in
(1) having vascular supply
(2) being modified leaves
(3) lacking bark (4) all are correct.

47. A deep seated, vascular structure that represents stem
(1) spine (2) thorn
(3) prickle (4) branch

48. Tendril is axillary in
(1) *Passiflora* (2) *Bougainvillea*
(3) Citrus (4) *Antigonon*

49. Stolon differs from runner in being
(1) shorter (2) longer
(3) underground (4) capable of arching

50. A runner of water with one thick internode, found in aquatic rosette plants like *Eichhorina* (water hyacinth) is called
(1) stolon (2) offset
(3) both correct (4) trailer

51. In *Citrus*, *Duranta* and *Bougainvillea*, the thorns are the modified
(1) axillary buds (2) leaves
(3) roots (4) apical bud

52. The needle like cladodes of *Asparagus* are metamorphosed stem for
(1) reducing transpiration
(2) increasing photosynthesis
(3) protecting plant from browsing
(4) none of the above.

53. Phylloclade is found in
(1) *Opuntia, Casuarina, Euphorbia*
(2) only Cacti
(3) Cacti, *Asparagus*
(4) *Opuntia* and *Ruscus*

54. When the entire stem with its all branches become green, flat, fleshy leafy to do photosynthesis and leaves are modifed into spines, it is called
(1) turion (2) phylloclade
(3) phyllode (4) bulbils

55. A cladode (cladophyll) is green leaf like modified aerial stem and is
(1) thorn
(2) one internode long phyllode
(3) one or two internode long branch
(4) a leaf modification

56. The branching where main stem grows endlessly due to presence of a terminal bud, is

(1) cymose uniparous (2) racemose
(3) helicoid cyme (4) scorpioid cyme

57. In grasses, the vigorous and quick growth occurs due to
(1) sucker (2) runner
(3) stolon (4) offset

58. Which is the odd type of vegetable in a basket containing the following ?
(1) Radishes (2) Carrots
(3) Potatoes (4) Beet roots

59. Which part of leaf is sensitive to sleep and shock movements ?
(1) Pinnule (2) Pinna
(3) Pulvinus (4) Petiole

60. In *Eichhornia* (water hyacinth), the spongy, swollen *pulvinus* structure is
(1) petiole (2) leaf base
(3) rachis (4) pedicel

61. The cord like tendrils in *Smilax* are
(1) leaflet tendrils (2) leaf tendrils
(3) stipular tendrils (4) stem tendrils

62. In which plant stipules become leaf like for photosynthesis ?
(1) Pea (2) *Zizyphus*
(3) Rose (4) *Smilax*

63. Choose the correct statement.
(1) Phylloclade is stem and phyllode is petiole.
(2) Phyllode has nodes and internodes and bears flowers.
(3) Phylloclade bears bud in its axil.
(4) Phyllode is never vertical in position.

64. The phyllotaxy in which two leaves arise from a bud at each node is
(1) whorled (2) alternate
(3) opposite (4) none of these

65. A dicot leaf with parallel venation is
(1) Colocasia (2) Alocacia
(3) *Eryngium* (4) All correct

66. A monocot leaf has parallel venation but there are some monocot leaves which have reticulate venation *viz.*
(1) *Calophyllum* (2) Corymbium
(3) *Dioscorea* (Yams) (4) All the above

67. Arrangement of young leaves with respect to each other in a bud is called
(1) aestivation (2) vernation
(3) phyllotaxy (4) venation

68. Phyllotaxy is
(1) arrangement of young leaves in bud
(2) arrangement of mature leaves on branches
(3) arrangement of branches
(4) arrangement of floral leaves in a floral bud

69. What type of venation is found in Banana (*Musa*) ?
(1) Unicostate reticulate
(2) Unicostate parallel
(3) Divergent reticulate
(4) Divergent parallel

70. When incision in a leaf is more than half way towards the midrib it is called
(1) Pinnatisect (2) Pinnatipartite
(3) Pinnatifid (4) Palmatipartite

71. The dividing of the lamina upto half way in a multicostate veined leaf is
(1) palmatisect (2) palmatifid
(3) palmatipartite (4) pinnatipartite

72. Petiole is winged in
(1) *Citrus* leaf (2) Pea leaf
(3) *Eucalyptus* leaf (4) None of these

73. In *Nepenthes Khasiana* found in Assam/ north east India, colourful lid of pitcher is formed by
(1) leaf (2) petiole
(3) lamina (4) leaf apex

74. Phyllode (Phythode) is leaf like and derived from
(1) stem (2) root
(3) petiole and rachis (4) bud

75. Formation of phyllode in Australian *Acacia* is a mechanism to
(1) protect plant from browsing animals
(2) reduce rate of transpiration
(3) increase rate of photosynthesis
(4) all are correct.

76. Petiole becomes tendrillar to help in climbing in
(1) Smilax
(2) *Tropaeolum* (Garden Nasturtium)
(3) Both (1) and (2) (4) Gloriosa

77. In Cacti, leaves are modified into
(1) hooks (2) phylloclade
(3) spines (4) thorns

78. A branch of simple leaves is distinct from a Pinnate compound leaf in having

(1) axillary buds in the axil of its leaves
(2) flowers
(3) apical bud (4) all correct

79. When petiole bears leaflets at its tip, it is a
(1) simple leaf
(2) pinnate compound leaf
(3) palmate compound leaf
(4) isobilateral leaf

80. In a Pinnate compound leaf, leaflets are borne in
(1) acropetal manner
(2) basipetal manner
(3) one plane (4) none of these

81. Among the following finely dissected leaves are found in
(1) free floating plants
(2) submerged hydrophytes
(3) emerged hydrophytes
(4) all of the above

82. A pair of insectivorous plants is
(1) *Drosera* and *Rafflesia*
(2) *Nepenthes* and Bladderwort
(3) *Dionaea* and *Viscum*
(4) *Rafflesia* and Venus fly trap

83. Petiole of Australian *Acacia* helps in
(1) respiration (2) photosynthesis
(3) transpiration (4) secretion

84. Water plants usually have well developed
(1) root system (2) stem
(3) vascular system
(4) leaves

85. Onion stores food in
(1) shoot (2) stem
(3) fleshy scales (4) root

86. Leaf in the axil of which flower arises
(1) Sporophyll (2) Bract
(3) Hypsophyll (4) Cataphyll

87. Leaves of *Utricularia* are modified into
(1) hooks (2) tendrils
(3) bladders (4) pitchers

88. Inflorescence is
(1) arrangement of flowers on peduncle/floral axis
(2) a system of branches bearing flowers
(3) a branch bearing flowers in definite manner
(4) all the above

89. In case of Corymb Inflorescence
(1) all flowers are covered by a sheath
(2) all flowers are brought more or less to the same level
(3) all flower arise from a common point
(4) none of the above

90. The primary stem which supports an inflorescence is called
(1) pedicel (2) peduncle
(3) vegetative shoot (4) receptacle

91. The inflorescence where flowers arise from a common point, is known as
(1) umbel (2) corymb
(3) spike (4) spadix

92. Choose the correct statement.
(1) Acropetal arrangement of flower is homologous to centripetal arrangement
(2) Acropetal is homologous to centrifugal arrangement
(3) Acropetal is homologous to cymose inflorescence
(4) None of the above.

93. The inflorescence in *Coriandrum* is
(1) panicle (2) capitulum
(3) cyme (4) compound umbel

94. The inflorescence which is a compact unisexual spike which matures and falls down as a single unit is
(1) spike (2) spadix
(3) catkin (4) typical raceme

95. Large green coloured bract in spadix is known as
(1) epicalyx (2) spathe
(3) involucre (4) involucel

96. A plant bearing solitary inflorescence is
(1) *Hibiscus rosa sinensis*
(2) *Salvia officinalis*
(3) *Tulsi* (4) *Sunflower*

97. Inflorescence in *Musa paradisiaca* (banana) is a
(1) raceme (2) catkin
(3) spadix (4) verticellaster

98. The unit of inflorescence in grasses / graminea (poaceae) is
(1) umbel (2) cymose
(3) spikelet (4) raceme

99. The type of inflorescence wherein the main axis has limited growth and ends in a flower is termed

(1) racemose (2) cymose
(3) hypanthodium (4) cyathium

100. Cyathium inflorescence shows
(1) similar type of flowers
(2) one central male flower surrounded by many male flowers
(3) one central female flower surrounded by many male flowers
(4) sessile flowers on long axis

101. In 'Tulsi' (*Ocimum*) of Labiatae the inflorescence is
(1) cyathium (2) verticillaster
(3) hypanthodium
(4) raceme of racemes *(Haryana 2001)*

102. Three types of flowers are found in
(1) capitulum (2) hypanthodium
(3) catkin (4) verticillaster

103. Gall flowers are found in
(1) spadix (2) hypanthodium
(3) catkin (4) umbel

*104. If one stamen in cyathium inflorescence produce 20 pollens then how many pollens will be produced by each male flower
(1) 20 (2) 100
(3) Indefinite (4) 40

105. An achlamydeous (naked) flower is found in
(1) head (2) cyathium
(3) umbel (4) hypanthodium

106. A beautiful whorl which encloses whole of the inflorescence is
(1) bract (2) spadix
(3) appendix (4) involucre

107. Which of the following pairs is not correct ?
(1) Corymb — Candituft
(2) Capitulum — Sunflower
(3) Catkin — Mulberry
(4) Raceme — Wheat

108. Spadix is the inflorescence of
(1) Maize, Coconut, Cauliflower
(2) Palm, Colocasia, Banana
(3) Fig, Aroids, Mulberry
(4) Arisaema, Rice, Banana

109. The receptacle is flattened at the top and bears numerous sessile flowers in centripetal manner in
(1) cynathium (2) catkin
(3) umbel (4) capitulum

110. If a plant bears unisexual, bisexual and even neutral flowers, it is called
(1) bisexual (2) polygamous
(3) bigamous (4) monoecious

111. A flower with carpels, stamens, petals is said to be
(1) complete (2) perfect
(3) monoecious (4) unisexual

112. Thalamus (torus/receptacle) is condensed end of floral axis on which floral leaves are inserted. This thalamus represents
(1) 4 internodes (2) 3 internodes
(3) 2 internodes (4) 1 internodes

113. When both sexes are absent from a flower or are non-functional, the flower is said to be
(1) neuter (2) incomplete
(3) unisexual (4) imperfect

114. When petals are green the term used is
(1) petaloid (2) sepaloid
(3) coralloid (4) haploid

115. When male and female flowers are found in separate plants, it is termed as
(1) monoecious (2) dioecious
(3) heteroecious (4) autoecious

*116. Anthesis is
(1) opening of flower bud
(2) floral bud formation
(3) stigma receptor
(4) meiosis in spore mother cell.

117. If a flower exhibits bilateral symmetry only *i.e.*, symmetry of one plane, it is called
(1) actinomorphic (2) zygomorphic
(3) asymmetrical (4) dimorphic

118. In papilionaceous flower the innermost petal unite to form a boat shaped structure called
(1) alae (2) carina
(3) vaxillum (4) wings

119. Radial symmetry is
(1) zygomorphy (2) actinomorphy
(3) spirocyclic (4) not found in plants

120. Vexillum, alea and keel are
(1) androecium (2) gynoecium
(3) corolla (4) calyx

*104. In cyathium, each male flower is represented by a single stamen.
*116. Anthesis is emergence of anthers from corolla tube *i.e.*, opening of flower bud.

121. Epicalyx is a characteristic of Malvaceae. It is
(1) a whorl of bracts
(2) additional whorl of calyx like organs
(3) involucre (4) a whorl of corolla

122. When two of the sepals or petals are outer, two are inner and one is partly outer partly inner, this condition is known as
(1) imbricate aestivation
(2) quincuncial aestivation
(3) twisted aestivation
(4) valvate aestivation.

123. In a typical flower, the ovary is superior and other whorls are inferior. Such flower is said to be
(1) hypogynous (2) epigynous
(3) polygynous (4) perigynous

124. In bisexual flowers when the gynoecium matures earlier than the androecium, it is called
(1) heterogamy (2) autogamy
(3) protogyny (4) protandry

125. The absence of any one or more of the floral organs makes the flower
(1) imperfect (2) incomplete
(3) indeterminate (4) dioecious

126. Polysepalous represents the presence of
(1) fused sepals (2) free sepals
(3) hairy sepals (4) (1) and (3)

127. The term used for fused petals is
(1) polypetalous (2) gamopetalous
(3) gamophyllous (4) syngenesious

128. The term used when there is no distinction between non essential or accessory floral organs, is
(1) epicalyx (2) perianth
(3) persistent calyx (4) scaly leaves

129. The individual parts of the perianth are known as
(1) sepals (2) petals
(3) tepals (4) carpels

130. Cruciform corolla is that where
(1) petals are arranged diagonally
(2) one petal ovarlaps another
(3) there are only two petals
(4) petals form a bell shaped structure

131. When stamens are attached to perianth, it is known as
(1) epipetalous (2) episepalous
(3) gynandrous (4) epiphyllous

132. When the stamens are united throughout their whole length by filaments and anthers the condition is known as
(1) synandrous (2) syngenesious
(3) diadelphous (4) monadelphous

133. Syngenesious condition is found in
(1) Asteraceae (2) Labiatae
(3) Solanaceae (4) Fabaceae

134. In one of the following plants connective is elongated, one end of connective bears a fertile lobe and other a sterile plate.
(1) Sunflower (2) *Salvia*
(3) *Petunia* (4) *Ficus*

135. Stamens fused with petals are known as
(1) epipetalous (2) gamopetalous
(3) polypetalous (4) epiphyllous

136. Monoadelphous term is used to indicate
(1) anthers fused in a single group
(2) filaments fused in a single group
(3) both anthers and filaments fused in a single group
(4) only one whorl of stamens in a flower

137. A stamen with two anther lobes and four pollen sacs is called
(1) monothecous (2) dithecous
(3) exserted (4) tetrathecous

138. What will we call this condition of A_{2+4} which is a characteristic of cruciferae ?
(1) Didynamous (2) Tetradynamous
(3) Homostamenous
(4) Obdiplostamenous

139. Stamens with free anthers but filaments fused into a number of groups are
(1) polyadelphous (2) diadelphous
(3) monoadelphous (4) syngenesious

140. When all carpels are free from each other, the condition is known as
(1) polycarpellary (2) syncarpous
(3) apocarpous (4) bicarpellary

141. The ovary which is unilocular with placentae present on the walls represents
(1) axile placentation
(2) parietal placentation
(3) apical placentation
(4) free central placentation

142. A single longitudinal placenta along the wall of ovary represents
(1) marginal placentation

(2) parietal placentation
(3) free central placentation
(4) superficial placentation

143. In wheat Jowar/grasses the anthers are called
(1) basifixed (2) adnate
(3) versatile (4) dorsifixed

*144. Clove is a part of
(1) flower (2) thalamus of a flower
(3) root (4) seed

145. What type of placentation is seen in Sweet Pea ?
(1) Free central (2) Marginal
(3) Basal (4) Axile

146. Floral formula fails to indicate
(1) epiphylly and epipetaly
(2) floral symmetry
(3) cohesion of stamens and carpels
(4) aestivaton and placentation

147. Largest family of Angiosperms is
(1) Gramineae (2) compositae
(3) Cruciferae (4) orchidaceae

148. Monocarpellary ovary, diadelphous androecium and marginal placentation is found in
(1) Cruciferae (2) Compositae
(3) Liliaceae (4) Papilionaceae

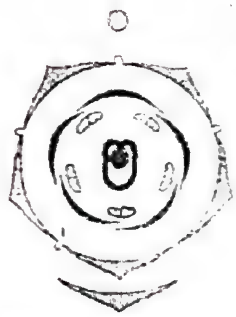
149. Replum is characteristic of ovary of
(1) Cruciferae (2) Compositae
(3) Labiatae (4) Liliaceae

150. Nicotine, chillies, tomatoes, reserpine, all are obtained from members of family
(1) Cucurbitaceae (2) Labiatae
*(3) Gramineae (4) Solanaceae

151. In the F.F. Br, ⊕, ⚥, $K_{(5)}$, $C_{(5)}$ $A_{(5)}$ $G_{(2)}$, What does $G_{(2)}$ mean ?
(1) two carpels, syncarpous, ovary superior
(2) two carpels, syncarpous ovary inferior
(3) two carpels, apocarpous ovary superior
(4) bicarpellary, apocarpous ovary inferior

152. The family comprising the largest number of genera and species in monocots is
(1) Orchidaceae (2) Liliaceae
(3) Poaceae (4) Musaceae

153. Choose the correct description of the flower depicted in the floral diagram given below

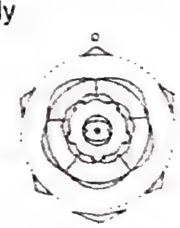


(1) United, valvate sepals; free, twisted petals; free stamens; unilocular ovary with marginal placenta.
(2) United , valvate sepals; free, imbricate petals; free stamens; unilocular ovary with axile placenta.
(3) United, valvate sepals; free, imbricate petals, epipetalous stamens; unilocular ovary with marginal placenta.
(4) United, valvate sepals; free, imbricate petals; free stamens; unlocular ovary with marginal placenta

154. A flower characterised by monodelphous tubular stamen belongs to
(1) Solanaceae (2) liliaceae
(3) Malvaceae (4) Brassicaceae

155. One of the following statements does not apply to the Cruciferae family ?
(1) Flowers are tetramerous
(2) Ovary shows false septum (replum) and parietal placentation
(3) Fruit is siliqua/silicula
(4) Androecium is didynamous

156. The floral formula of the given floral diagram is most likely



(1) Br ⚥, K_{pappus}, $\overset{\frown}{C_{(5)} A_{(5)}}$ $G_{(\bar{2})}$
(2) Br K_{Pappus} , C_2 A_0 $G_{(\bar{2})}$
(3) Br ⚥. K_{pappus} C_5 A_5 $G_{(\bar{1})}$
(4) Br ⚥, K_{Pappus} $\overset{\frown}{C_{(5)} A_{(5)}}$ G_0

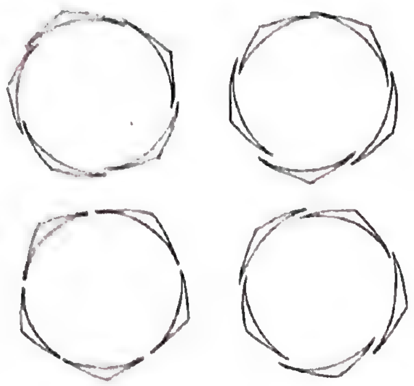
*144. Clove is unopened flower bud.

(5) Br ⚥, $K_{Pappus}\ \widehat{C_{(5)}\ A_5}\ G_{(\bar{2})}$

157. In which of the following aestivation, sepal/ petal's one margin covers the other and its second margin is covered by previous one ?
(1) Valvate (2) imbricate
(3) Twisted (4) Quincunical

158. Ovary in Solanaceae is
(1) bicarpellary, syncarpus, superior
(2) monocarpellary, syncarpous, superior
(3) tricarpellary, syncarpous, superior
(4) multicarpellary, syncarpous, superior

159. Out of four aestivations of petals given below, which one is found in Malvaceae



(1) 1 (2) 2 (3) 3 (4) 4

160. Which type of aestivation is shown in the diagram?
(1) Valvate
(2) Descending imbricate
(3) Aescending imbricate
(4) Conduplicate valvate

161. Adhesion in a flower is
(1) union of dissimilar parts
(2) union of similar parts
(3) aggregation of similar parts
(4) aggregation of dissimilar parts

162. Basal placentation occurs in an ovary which is
(1) unilocular (2) bilocular
(3) multilocular (4) lateral

163. Pentamerous, actinomorphic flowers and bicarpellary ovary with oblique septa and fruit a capsule or berry are characteristic features of
(1) Solanaceae (2) Liliaceae
(3) Asteraceae (4) Brassicaceae

164. The fruit which develops from ovary in collaboration with any other floral part is called
(1) false fruit (2) simple fruit
(3) succulent fruit (4) dry fruit

165. Balausta fruit is found in
(1) Pepo (2) Pomegranate
(3) Orange (4) Pumpkin

166. The fruits which consist of numerous similar fruits, all of which developed from poly-carpellary apocarpous ovaries of a flower and mature together as a single unit is known as
(1) aggregate fruit (2) composite fruit
(3) dry fruit (4) schizocarpic fruit

167. The aggregates of simple fruitlets are called
(1) etaerio (2) aggregations
(3) fruitlet aggregation (4) follicles

168. When the fruit develops from a spike or catkin inflorescence, it is known as
(1) syconus (2) sorosis
(3) caryopsis (4) hesperidium

169. The single seeded indehiscent, dry and simple fruits developed from a single flower are called
(1) achenial fruits (2) capsular fruit
(3) schizocarpic fruits
(4) etaerio fruit

170. Name the only dry fruit where a fleshy edible part is present.
(1) Litchi (2) Tomato
(3) Cashewnut (4) Walnut

171. In Radish the fruit is
(1) lomentaceous pod (2) siliqua
(3) lomentaceous siliqua (4) silicula

172. The endocarp is membranous in
(1) Tomato (2) Date
(3) Mango (4) *Zizyphus*

173. A characteristic of drupe is
(1) stony mesocarp (2) stony endocarp
(3) fleshy seed coat (4) stony pericarp

174. In Banana, the skin of fruit represents
(1) epicarp
(2) outer part of epicarp
(3) fused eipicarp and thalamus
(4) mesocarp

175. None of pericarp layers is edible in case of
(1) Almond (2) *Zizyphus*
(3) Grape (4) Banana

176. Pome of apple is developed from
(1) superior ovary (2) inferior ovary

(3) bicarpellary syncarpous ovary
(4) none of the above

177. A fruit formed from a condensed inflorescence is termed as
(1) an etaerio of fruit
(2) a composite fruit
(3) an aggregate of fruit
(4) a simple fruit

178. Which of the following pairs is not correctly matched ?
(1) Tomato–berry (2) Mango–drupe
(3) Sunflower–cypsela (4) Fig–sorosis

179. The edible part of Peach is
(1) endocarp
(2) epicarp & mesocarp
(3) exocarp (4) pericarp

180. The fruit of jack fruit is a composite fruit called
(1) syconus (2) pome
(3) catkin (4) sorosis

181. The fruit of apple is said to be false because
(1) it's endocarp is cartilaginous
(2) it develops from a superior ovary
(3) it's actual fruit is located within an edible fleshy thalamus
(4) no part of fruit is edible

182. Mulberry fruit is
(1) simple fruit (2) dry fruit
(3) aggregate fruit (4) composite fruit

183. Berry is a fruit which is generally
(1) fleshy and many seeded
(2) fleshy and single seeded
(3) dry and single seeded
(4) dry and many seeded

184. One of the following is a false fruit
(1) Tomato (2) Stawberry
(3) Mango (4) Brinjal

185. Which one of the following is a true nut ?
(1) Cashewnut (2) Groundnut
(3) Cocunut (4) Areca nut

186. Which one of the following belong to the same category ?
(1) Cashewnut, coconut and chestnut
(2) Coconut, orange and tomato
(3) Betelnut, chestnut and coconut
(4) Mango, almond and coconut

187. Fruits developed from bicarpellary syncarpous ovary having one false septum are
(1) siliqua (2) achene
(3) capsule (4) all of these

188. Papaya (*Carica papaya*) is a fleshy fruit and is known as:
(1) pome (2) composite
(3) berry (4) drupe

189. A fruit developed from hypanthodium inflorescence is called
(1) Syconus (2) Caryopsis
(3) Hesperidium (4) Sorosis
(CBSE PMT Prelims 2009)

190. Geocarpic fruit is
(1) Potato (2) Peanut
(3) Onion (4) Garlic

191. Berries, drupes and pomes are
(1) simple dry fruits
(2) simple succulent fruits
(3) aggregate fruits
(4) composite fruits

*192. 3 eye spots on coconut fruit represent
(1) 3 ovaries
(2) bases of style of 3 carpels
(3) 3 septa of ovary
(4) 3 seeds

193. Edible part of a straw berry is
(1) cotyledons (2) endocarp
(3) mesocarp (4) juicy thalamus

194. Pepo is a fruit of
(1) Cruciferae (2) Leguminosae
(3) Cucurbitaceae (4) Liliaceae

195. Single seeded indehiscent fruit having stony endocarp is
(1) achene (2) nut
(3) drupe (4) both (i) and (2)

196. In Mango and Coconut, the fruit is known as
(1) Drupe (2) Pod
(3) Nut (4) Kernel
(CBSE Prelims 2011; HP PMT 2011)

197. Persistent calyx attached to the berry fruit of
(1) pear (2) apple
(3) brinjal (4) mango

198. Seed is a
(1) fertilized and ripened ovule
(2) fertilized and ripened ovary

*192. 3 eye spots on coconut fruit represent bases of styles of three carpels.

(3) developing ovule
(4) developing ovary

199. Seed is
(1) immature integumented ovary
(2) mature integumented megasporangium
(3) mature coated spore
(4) immature integumented ovule

200. The point where stalk of the seed is borne is
(1) chalaza (2) hilum
(3) micropyle (4) node

201. Place of origin of seed coats is known as
(1) chalaza (2) hilum
(3) node (4) micropyle

202. The part of embryo axis between radical and cotyledonary node is called
(1) epicotyl (2) hypocotyl
(3) hilum (4) raphe

203. The part of embryo axis between plumule and cotyledonary node is called
(1) epicotyl (2) hypocotyl
(3) hilum (4) raphe

204. Maize or wheat grain is a
(1) seed (2) cypsela
(3) single seeded fruit (4) an ovule

205. The radicle in maize has two coverings
(1) outer coleorhiza and inner root cap
(2) inner colerhiza and outer root cap
(3) outer coleoptile and inner root cap
(4) inner coleoptile and inner root cap

206. The reserve food material in bean seed is in it's
(1) plumule (2) radicle
(3) endosperm (4) cotyledons

207. After the seedling begins to photosynthesise, the cotyledons
(1) degenerate and fall off
(2) become pholem tissue
(3) change into root tissue
(4) change into foliage leaves

208. Perisperm is
(1) remnant of endosperm
(2) persistent nucellus
(3) peripheral part of endosperm
(4) disintegrated secondary nucleus

209. Food in albuminous seed is stored in
(1) testa (2) cotyledon
(3) endosperm (4) plumule

210. Micropyle of seed is involved in the passage of
(1) male gametes (2) pollen tube
(3) water (4) gases

211. Tegmen develops from
(1) inner integument (2) funiculus
(3) outer integument (4) chalaza

212. Aleurone layer in the grain helps in
(1) storage of food in endosperm
(2) protection of embryo
(3) utilization of stored food by secreting enzymes
(4) all the above

213. Coleoptile and coleorhiza are protective coverings in Maize grain. Which is true ?
(1) Coleorhiza is a covering on plumule
(2) Coleoptile is a covering on radicle
(3) Coleoptile is a covering on plumule
(4) Coleorhiza is a covering of endosperm

214. Dormancy of seeds may be due to
(1) impermeable hard seed coat
(2) growth inhibitors in seed coat
(3) immature embryo
(4) any of the above

215. Seed dormancy allows the plant to
(1) overcome unfavourable condition
(2) develop healthy seeds
(3) reduce viability
(4) prevent deterioration of seeds

216. The embryo axis is called
(1) plumule (2) epicotyl
(3) hypocotyl (4) tigellum

217. The mature fertilized egg, ovule and the ovary respectively give rise to
(1) embryo, seeds and fruit
(2) embryo, fruit, seed
(3) seed, fruit and embryo
(4) fruit, seed and embryo

218. The aleurone layer in maize grain is present in peripheral region of endosperm specially rich in
(1) lipids (2) auxins
(3) proteins (4) starch

219. To remove seed dormancy by mechanically removing of seed coat is called
(1) stratification (2) scarification
(3) vernalization
(4) photoperiodism

220. A monocot albuminous seed is
(1) Gram (2) Bean
(3) Maize (4) all of the above

221. Parachute mechanism of fruit dispersal as found in compositae is due to structure named
(1) bract (2) pappus
(3) coma (4) barbs

222. Hydrochory of coconut is due to
(1) Liquid endosperm
(2) Stony endosperm
(3) Fibrous mesocarp
(4) Papery epicarp

223. Self dispersal mechanism is called
(1) zoochory
(2) explosive mechanism
(3) forced zoochory
(4) hydrochory

224. Some plants protect their parts by growing under the ground. This is called
(1) Geocarpy (2) Geophily
(3) Geotropism (4) Geology

225. A tree that has strong erect stem with hollow internodes and solid nodes is known as
(1) caudex (2) deliquescent
(3) scape (4) culm
(J & K CET 2011)

226. The reason for successful establishment on land by seed plants is
(1) evolution of siphonogamy
(2) development of secondary growth
(3) presence of true conducting tissue
(4) all of the above

227. The main difference between biennials and perennials is that the perennials
(1) are trees
(2) show asexual structures
(3) do not die after seasonal production of fruits
(4) bear perennating underground structures

228. National flower of India is
(1) *Rafflesia* (2) *Nelumbium*
(3) *Rosa indica* (4) *Wolffia*

229. The largest and smallest flowers are of 1 metre and 0.1 mm size. They belong to
(1) *Wolffia* and *Sapria*
(2) *Rafflesia* and *Wolffia*
(3) *Rafflesia* and *Salvinia*
(4) *Rafflesia* and *Sapria*

230. Biennial plants are those which
(1) complete their life cycle in two years
(2) live for more than one year but less than two years
(3) produce flowers twice a year
(4) grow vegetatively in one season and produce flowers in next season

231. Read the following matches
(i) *Alstonia* - Whorled phyllotaxy
(ii) *Calotropis* - Opposite and decussatephyllotaxy
(iii) *Smilax* - Parallel venation
(iv) China rose - Opposite and superposedphyllotaxy
(v) Sunflower - Spiralphyllotaxy

Which of these are correct?
(1) (ii), (iii), (iv) & (v)
(2) (i), (ii) and (iv)
(3) (ii), (iii) and (iv)
(4) (i), (ii) and (v)

232. The family containing *Petunia* and its main characters are
(1) **Solanaceae** – 5 fused sepals; 5 fused petals; 5 epipetalous stamens; Bicarpellary gynoecium; Capsule or berry type fruit.
(2) **Poaceae** – Perianth – 2 or 3 lodicules; 3 stamens; Monocarpellary gynoecium; Caryopsis type fruit
(3) **Solanaceae**– 5 free sepals; 5 free petals; 5 epipetalous stamens; Pentacarpellary gynoecium; Capsule or berry type fruit.
(4) **Fabaceae**– 5 fused sepals; 5 free petals; 10 stamens – diadelphous; Monocarpellary gynoecium; Legume type fruit.

233. Read the following matches with reference to the fruit
(i) Fig - Syconus
(ii) Grape - Pome
(iii) Papaya - Berry
(iv) Mustard - Follicle

Which of these are correct?
(1) (i), (ii) and (iii)
(2) (ii), (iii) and (iv)
(3) (i) and (iii)
(4) (iii) and (iv)

*234. Read the following matches with reference to the fruits

Name	Type	Edible part
(i) Banana	Berry	Epicarp & mesocarp
(ii) Date palm	Berry	Pericarp
(iii) Water melon	Drupe	Mesocarp
(iv) Plum	Drupe	Epicarp and mesocarp

Which of these are correct?
(1) (i), (iii) and (iv) (2) (ii) and (iv)
(3) (ii), (iii) and (iv) (4) (iii) and (iv)

*235. The family containing garlic and its main characters are
(1) **Fabaceae** – 5 fused sepals; 5 free petals; 10 stamens diadelphous; Monocarpellary gynoecium; Legume type fruit; Marginal placentation.
(2) **Fabaceae**– 5 free sepals; 5 free petals; 10 stamens – diadelphous; Bicarpellary gynoecium; Legume type fruit; Marginal placentation.
(3) **Liliaceae**– Perianth – 6 tepals in two whorls; 6 stamens Bicarpellary gynoecium; Cypsela type fruit; Axile placentation.
(4) **Liliaceae**– Perianth – 6 tepals in two whorls; 6 stamens; Tricarpellary gynoecium; Capsule or berry type fruit; Axile placentation

236. Read the following matches regarding the fruits

Name	Type	Edible part
(i) Tomato	Berry	Pericarp & placentae
(ii) Pomegranate	Hesperidium	Seed coat
(iii) Apple	Pome	Thalamus
(iv) Coconut	Drupe	Endocarp

Which of these are correct?
(1) (i), (iii) and (iv) (2) (ii), (iii) and (iv)
(3) (i) and (iii) (4) (ii) and (iv)

237. Read the following matches with reference to the fruit

Name	Type	Edible part
(i) Cashew	Nut	Cotyledons
(ii) Guava	Berry	Thalamus and pericarp
(iii) Orange	Hesperidium	Placental hair
(iv) Mango	Drupe	Mesocarp

Which of these are correct?
(1) (i), (ii) and (iii)
(2) (i), (iii) and (iv)
(3) (i) and (iv) (4) All are correct

238. Read the following matches regarding the placentation
(i) Primrose - Free central
(ii) Pea - Marginal
(iii) Marigold - Basal
(iv) Poppy - Axile

Which of these are correct?
(1) (i), (ii) and (iii)
(2) (ii), (iii) and (iv)
(3) (i), (iii) and (iv)
(4) All are correct

*239. Inferior achenial one chambered and one seeded fruit derived from bicarpellary pistil with pericarp and seed-coat free. Which of the following fruit belongs to this category of fruits?
(1) Wheat (2) Mustard
(3) Pea (4) Sunflower

240. Go through the following matches
(i) Jasmine - Climber
(ii) Peppermint - Stolon
(iii) *Pistia* - Offset
(iv) *Chrysanthemum* - Sucker

Which of these are correct?
(1) (i), (ii) and (iii)
(2) (ii), (iii) and (iv)
(3) (i), (iii) and (iv)
(4) All are correct

241. Read the following matches regarding the fruits

*234. In banana mesocarp and endocarp are edible. Water melon is a berry.
*235. Characters of Family Fabaceae are also correct in the option (1), but garlic belongs to the family Liliaceae.
*239. It is a cypsela.

Name	Type	Edible part
(i) Pine apple	Syconus	Fleshy peduncle
(ii) Cherry	Drupe	Mesocarp and endocarp
(iii) Mulberry	Sorosis	Fleshy bracts, perianth and young seeds
(iv) Straw berries	Etaerio of achenes	Fleshy thalamus & seeds

Which of these are correct?

(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (i) and (iii) (4) (iii) and (iv)

*242. Read names of the following plants
(i) *Nicotiana tobacum*
(ii) Candytuft (iii) Brinjal
(iv) *Zinnia* (v) *Capsicum*

Which of these belong to the family Solanaceae?
(1) (i), (ii) and (iii)
(2) (i), (ii) and (v)
(3) (i), (ii), (iii) and (v)
(4) (i), (iii), (v)

243. Go through the following matches
(i) *Cassia* – Imbricate aestivation
(ii) Lady finger – Twisted aestivation
(iii) *Calotropis* – Vexillary aestivation
(iv) Lily – Epipetalous stamens
(v) *Alstonia* – Whorled aestivation
(vi) Silk cotton – Pinnately compound leaf

Find out the correct matches
(1) (i), (iii), (v), (vi) (2) (ii), (iv), (v), (vi)
(3) (i), (ii) & (v) (4) (iii), (iv), (v), (vi)

244. Read the names of following plants
(i) *Gloriosa*
(ii) *Aloe barbadensis*
(iii) *Atropa belladona*
(vi) *Colchicum autumnale*
(v) *Asparagus*
(vi) *Withania somnifera*

Which of these belong to the family Liliaceae?

(1) (i), (ii), (iii), (iv) (2) (i), (ii), (iv), (v)
(3) (i), (ii), (v), (vi) (4) (ii), (iv), (v), (vi)

245. Read the following matches

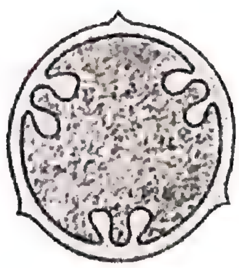
Family	Androecium	Fruit
(i) Solanaceae	Stamens six, epitepalous	Berry or capsule
(ii) Fabaceae	Ten stamens, diadelphous	Legume
(iii) Liliaceae	Stamens six, 3 + 3	Capsule or berry

Find out the correct matches
(1) (i) & (ii) (2) (ii) & (iii)
(3) (ii) only (4) All are correct

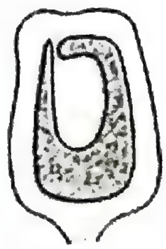
246. Go through the following matches regarding the flower
(i) Mustard - Epigynous
(ii) Plum - Perigynous
(iii) *Hibiscus* - Epigynous
(iv) Peach - Perigynous

Which of these are correct?
(1) (ii), (iii) and (iv) (2) (ii) and (iv)
(3) (iii) and (iv) (4) (i), (iii) and (iv)

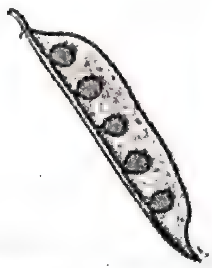
247. Go through the following figures depicting types of placentation



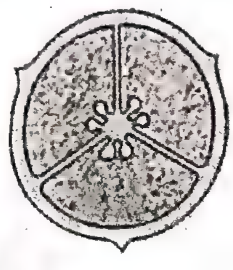
(i)



(ii)

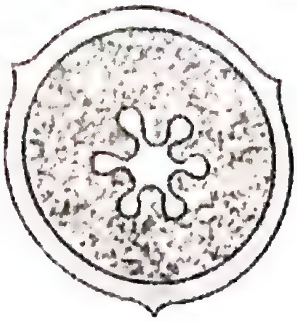


(iii)



(iv)

*242. Candytuft belongs to Brassicaceae and Zinnia belongs to Asteraceae.



(v)

Choose the option which correctly tells the placentation in order

(1) Parietal; Axile; Marginal; Basal; Freecentral

(2) Free central; Marginal; Basal; Axile; Parietal

(3) Parietal; Basal; Marginal; Axile; Free central

(4) Axile; Basal; Marginal; Freecentral; Parietal

248. In wheat and rice

(1) Fruit is multiseeded

(2) Seed coat and pericarp are separate

(3) Perisperm is fused with seed coat

(4) Pericarp is fused with seed coat

249. Which of the following is a characteristic of sorosis?

(1) True fruit surrounded by fleshy edible thalamus

(2) Edible bracts

(3) Multi-seeded fruit development from a monocarpellary pistil

(4) Development from a spike or spadix

250. Morphologically, the spice-yielding part of turmeric is

(1) Seed (2) Root

(3) Dried fruit (4) Rhizome

251. Which one of the following plants has ovary superior, monocarpellary and unilocular with several ovules on marginal placenta?

(1) *Triticum* (2) *Helianthus annus*

(3) *Pisum sativum* (4) *Allium cepa*

252. By the presence of which of the following can the family Brassicaceae be immediately identified?

(1) Inferior ovary and cruciform corolla

(2) Tetradynamous stamens and axile placentation

(3) Tetradynamous stamens and replum

(4) Cruciform corolla and indehiscent fruit

253. Edible part of cabbage is

(1) Fruit (2) An inflorescence

(3) A vegetative bud (4) A flower

254. Stem is most reduced in

(1) Phylloclade (2) Bulb

(3) Corm (4) Rhizome

255. Twiners climb over the support with the help of

(1) Adventitious roots (2) Tendrils

(3) Stem itself (4) Hooks

256. In *Agave*, bulbil is a modification of

(1) Vegetative bud (2) Cauline bud

(3) Terminal bud (4) Floral bud

257. Ptyxis refers to

(1) Cotyledonary leaves

(2) Arrangement of leaves on stem

(3) Coiling of leaves in the bud condition

(4) None of the above

258. One can distinguish a leaflet from leaf by the absence of

(1) Midrib (2) Petiole

(3) Axillary bud (4) Venation

*259. Find the set of composite fruits among those listed below

(i) Raspberry (ii) Mulberry

(iii) Jackfruit (iv) Blackberry

(v) Pineapple (vi) Fig.

(1) (i), (ii), (iii), (iv), (v), (vi)

(2) (i), (ii), (iii), (v), (vi)

(3) (ii), (iii), (v), (vi)

(4) (iii), (v), (vi)

260. Plants with inferior ovary always bear

(1) Pseudocarps (2) berries

(3) Aggregate fruits (4) seedless fruits

261. The ovary in hypogynous flowers is said to be

(1) Half inferior (2) Inferior

(3) Superior (4) None of the above

(HP PMT 2010)

262. Go through the following matches

(i) Wild strawberry - Stolon

(ii) *Eichhornia* - Offset

(iii) *Chrysanthemum* - Twiner

(iv) Pine apple - Offset

*259. Raspberry and blackberry are aggregate fruits [Etaerio of drupes]. Pineapple, jackfruit and mulberry are sorosis while fig is a syconus.

Which of these are correct?
(1) (i) and (ii) (2) (ii) and (iii)
(3) (iii) and (iv) (4) (i) and (iii)

263. Go through the following matches
(i) Mint - Sucker
(ii) Lotus - Rhizome
(iii) Zamikand - Rhizome
(iv) Pine apple - Sucker
Which of these are correct?
(1) (i), (ii), (iii) (2) (ii), (iii) and (iv)
(3) (i), (ii) and (iv) (4) All are correct

264. Go through the following matches
(i) *Colocasia* - Corm
(ii) Ginger - Rhizome
(iii) Turmeric - Corm
(iv) *Canna* - Rhizome
Which of these are correct?
(1) (i), (ii) and (iii) (2) (i) and (ii)
(3) (ii), (iii) and (iv) (4) (i), (ii) and (iv)

265. Read the following matches
(i) Lily – Compound tunicated bulb
(ii) Potato – Tuber
(iii) *Allium cepa* – Simple tunicated bulb
(iv) *Allium sativum* – Scaly bulb
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (ii) and (iii) (4) (iii) and (iv)

266. Read the following matches
(i) Guava - Spiral phyllotaxy
(ii) *Ruscus* - Cladode
(iii) *Opuntia* - Phylloclades
(iv) Mustard - Spiral phyllotaxy
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (i), (iii) and (iv) (4) (i), (ii) and (iv)

267. Read the following matches
(i) Wild pea – Petiolar tendril
(ii) Sweet pea – Leaflet tendril
(iii) Gloriosasuperba – Stipular tendril
(iv) Australian Acacia – Phyllodes
Which of these are correct?
(1) (ii) and (iii) (2) (i) and (iv)
(3) (ii), (iii) and (iv) (4) (ii) and (iv)

268. Read the following matches
(i) *Parkinsonia* - Phyllodes
(ii) *Utricularia* - Leaf bladder
(iii) *Aloe* - Succulent leaves
(iv) *Opuntia* - Tendril
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (i), (iii) and (iv) (4) All are correct

269. Read the following matches
(i) *Datura* - Actinomorphic flower
(ii) *Canna* - Zygomorphic flower
(iii) Gulmohur - Zygomorphic flower
(iv) *Cassia* - Asymmetric flower
Which of these are correct?
(1) (i), (ii) and (iii) (2) (i) and (iii)
(3) (ii) and (iv) (4) (ii), (iii) and (iv)

270. Go through the following matches
(i) China rose - Twisted aestivation
(ii) *Calotropis* - Valvate aestivation
(iii) Gulmohur - Ascending imbricate aestivation
(iv) Pea - Descending imbricate aestivation
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (i), (iii) and (iv) (4) All are correct

271. Go through the following matches
(i) Cotton - Open aestivation
(ii) Lady finger - Quincuncial aestivation
(iii) *Cassia* - Ascending imbricate aestivation
(iv) Bean - Descending imbricate aestivation
Which of these are correct?
(1) (i), (iii) & (iv) (2) (iii) and (iv)
(3) (ii), (iii) and (iv) (4) All are correct

272. Read the following matches
(i) *Salvia* - Didynamous stamen
(ii) China Rose - Monoadelphous
(iii) Citrus - Polyadelphous
(iv) Candytuft - Umbel
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (i), (iii) and (iv) (4) All are correct

273. Go through the following matches:
(i) *Poinsettia* - Cyathium
(ii) *Ocimum sanctum* - Cyathium

(iii) *Salvia* - Verticillaster
(iv) Fig - Verticillaster

Which of these are correct?
(1) (i), (ii) and (iii) (2) (i) and (iii)
(3) (ii) and (iii) (4) (ii), (iii) and (iv)

274. Read the following matches regarding the placentation
(i) Argemone - Axile
(ii) China rose - Free central
(iii) Lemon - Axile
(iv) Mustard - Parietal

Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (ii) and (iv) (4) (iii) and (iv)

275. Read the following matches regarding the placentation
(i) *Dianthus* - Free central.
(ii) *Cannabis* - Marginal
(iii) Sunflower - Basal
(iv) *Cucurbita* - Axile

Which of these are correct?
(1) (i), (ii) and (iii) (2) (i) and (iii)
(3) (ii) and (iii) (4) (ii), (iii) & (iv)

276. Select the wrong match
(1) Castor oil seed – Dicot, endospermic and perispermic
(2) Bean seed – Dicot and non-endospermic
(3) Maize – Monocot and endospermic
(4) Mustard – Dicot and endospermic

277. Read the following matches

Family	Symmetry	Petals
(i) Solanaceae	Zygomorphic	5, poly-etalous
(ii) Fabaceae	Zygomorphic	5, poly-petalous
(iii) Brassicaceae	Actinomorphic	4, poly-petalous

Which of these are correct?
(1) (i) and (ii) (2) (ii) and (iii)
(3) (i) and (iii) (4) All are correct

278. Consider the following statements
A. Mustard flower is hypogynous
B. Rose flower is perigynous
C. China Rose flower is hypogynous

Which of the statements given above is/are correct?
(1) A and C (2) B and C
(3) A, B & C (4) None

279. An example of a seed with endosperm, perisperm and caruncle is
(1) Lily (2) Castor
(3) Cotton (4) Coffee

280. Cotyledons and testa respectively are edible parts in
(1) French bean and coconut
(2) Cashew nut and litchi
(3) Groundnut and pomegranate
(4) Walnut and tamarind

***281.** The floral formula $\oplus ⚥ K_{(5)}\ \widehat{C_{(5)}\ A_5}\ \underline{G_{(2)}}$ is that of
(1) Sunhemp (2) Tobacco
(3) Tulip (4) Soyabean

***282.** An example of axile placentation is
(1) Lemon (2) Marigold
(3) Argemone (4) Dianthus

283. The petiole modified into leaf like structure is known as
(1) Phylloclade (2) Phyllode
(3) Cladode (4) Cladophyll

284. Which one of the following is a xerophytic plant in which the stem is modified into the flat green and succulent structure?
(1) *Opuntia* (2) *Casuarina*
(3) *Hydrilla* (4) *Acacia*
(CBSE Main PMT 2010)

285. Consider the following four statements A, B, C and D and select the right option for two correct statements.
(A) In vexillary aestivation, the larger posterior petal is called – *standard*, two lateral ones are *wings* and two small anterior petals are termed *keel*.
(B) The floral formula for Liliaceae is

$$\oplus ⚥\ P_{3+3}\ A_{3+3} + G_3$$

*281. This is the floral formula of family Solanaceae.
*283. Marigold – Basal; Argemone – Parietal; Dianthus – Free central

(C) In pea flower the stamens are monadelphous

(D) The floral formula for Solanaceae is

$$\oplus\ ⚥\ K_{(3)}\, C_{(3)}\, A_{(4)} + G_{(2)}$$

The correct statements are

(1) (A) and (C) (2) (A) and (B)
(3) (B) and (C) (4) (C) and (D)

(CBSE Main PMT 2010)

286. The scutellum observed in a grain of wheat or maize is comparable to which part of the seed in other monocotyledons?

(1) Plumule (2) Cotyledon
(3) Endosperm (4) Aleurone layer

(CBSE PMT Prelims 2010)

287. Keel is characteristic of the flowers of

(1) Bean (2) Gulmohur
(3) *Cassia* (4) *Calotropis*

(CBSE PMT Prelims 2010)

288. A single-seeded, dry, non-dehiscent fruit in which pericarp is united with seed is known as

(1) Caryopsis (2) Cypsela
(3) Achene (4) Loment

(Chandigarh CET 2010)

289. Capitulum inflorescence is characteristic feature of the family

(1) Asteraceae (2) Moraceae
(3) Poacaeae (4) Brassicaceae

(Chandigarh CET 2010)

290. Aestivation found in pea flowers is

(1) Vexillary (2) Imbricate
(3) Twisted (4) Valvate

(HP PMT 2010)

291. Which one of the following pairs is wrongly matched while the remaining three are correct?

(1) *Penicillium* – Conidia
(2) Water Hyacinth – Runner
(3) *Bryophyllum* – Leaf buds
(4) *Agave* – Bulbils

(CBSE Main PMT 2011)

*292. Whorled, simple leaves with reticulate venation are present in

(1) *Calotropis* (2) Neem
(3) China Rose (4) *Alstonia*

(CBSE Main PMT 2011)

*293. Sweet potato is homologous to

(1) Potato (2) Colocasia
(3) Ginger (4) Turnip

(CBSE Main PMT 2011)

*294. Which one of the following statements is correct?

(1) In tomato, fruit is a capsule
(2) Seeds of orchids have oil-rich endosperm
(3) Placentation in *primose* is basal
(4) Flower of tulip is a modified shoot

(CBSE PMT Prelims 2011)

295. The correct floral formula of chilli is

(1) $\oplus\ ⚥\ K_{(5)}\, C_5\, A_5\, \underline{G}_{(2)}$

(2) $\oplus\ ⚥\ K_{(5)}\, C_{(5)}\, A_5\, \underline{G}_{(2)}$

(3) $\oplus\ ⚥\ K_{(5)}\, C_{(5)}\, A_{(5)}\, \underline{G}_2$

(4) $\oplus\ ⚥\ K_5\, C_5\, A_{(5)}\, \underline{G}_2$

(CBSE PMT Prelims 2011)

*296. Flowers are zygomorphic in

(1) Mustard (2) Gulmohur
(3) Tomato (4) Datura

(CBSE PMT Prelims 2012)

297. Members of plants which provide pulses belong to family

(1) Asteraceae (2) Fabaceae
(3) Poacea (4) Solanaceae

(Chandigarh CET 2011)

298. In some plants such as Rhizophora growing in swampy areas, many roots come out of the ground and grow vertically upwards. Such roots are called

(1) Pneumatophores
(2) Prop roots
(3) Stilt roots
(4) None of the above

(HP PMT 2011)

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*292. Calotropis has opposite phyllotaxy. China Rose has alternate phyllotaxy. Neem has pinnately compound leaves.
*293. Carrot, Turnip & sweet potato are storage roots. Colocasia, Ginger, Potato, Zamikand are storage stems.
*294. In tomato fruit is a berry. Orchid seeds are non endospermic. Placentation in primose is free central
*296. Gulmohur, Pea, Bean and Cassia are zygomorphic. Mustard, Tomato and Datura are Actinomorphic.

*299. How many plants in the list given below have marginal placentation?

Mustard, Gram, Tulip, Asparagus, Arhar, Sun hemp,Chilli, Colchicine, Onion, Moong, Pea, Tobacco, Lupin

(1) Six (2) Three
(3) Four (4) Five

(CBSE Main PMT 2012)

*300. Which one of the following organisms is correctly matched with its three characteristics?

(1) Onion : Bulb, Imbricate aestivation, Axile placentation
(2) Maize : C_3 pathway, Closed vascular bundles, Scutellum
(3) Pea : C_3 pathway, Endospermic, seed, Vexillary aestivation
(4) Tomato : Twisted aestivation, Axile placentation, Berry

(CBSE Main PMT 2012)

*301. How many plants in the list given below have composite fruits that develop from an inflorescence?

Walnut, poppy, radish, fig, pineapple, apple, tomato, mulberry

(1) Five (2) Two
(3) Three (4) Four

(CBSE PMT Prelims 2012)

302. Gymnosperms are also called soft wood spermatophytes because they lack

(1) Phloem fibres
(2) Thick-walled tracheids
(3) Xylem fibres
(4) Cambium (CBSE PMT Prelims 2012)

*303. Cymose inflorescence is present in

(1) *Sesbania*
(2) *Trifolium*
(3) *Brassica* (4) *Solanum*

(CBSE PMT Prelims 2012)

304. Vexillary aestivation is characteristic of the family

(1) Asteraceae
(2) Solanaceae
(3) Brassicaceae
(4) Fabaceae

(CBSE PMT Prelims 2012)

305. The gynoecium consists of many free pistils in flowers of

(1) Tomato (2) *Papaver*
(3) *Michelia* (4) *Aloe*

(CBSE PMT Prelims 2012)

306. Which one of the following is correctly matched?

(1) Ginger – Sucker
(2) Chlamydomonas – Conidia
(3) Yeast – Zoospores
(4) Onion – Bulb

(CBSE PMT Prelims 2012)

307. Phyllode is present in

(1) *Euphorbia*
(2) Australian Acacia
(3) *Opuntia* (4) *Asparagus*

(CBSE PMT Prelims 2012)

*308. Pulvinate leaf base is found in this plant

(1) *Lycopersicum* (2) *Trifolium*
(3) *Nicotiana* (4) *Petunia*

(HP PMT 2012)

309. In china rose the flowers are

(1) Zygomorphic, hypogynous with Imbricate aestivation
(2) Zygomorphic, epigynous with twisted aestivation
(3) Actinomorphic, hypogynous with twisted aestivation
(4) Actinomorphic, epigynous with valvate aestivation

(NEET 2013)

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*299. Marginal placentation is a characteristic of Fabaceae. Cruciferae (Mustard) has parietal placentation. Solanaceae & Liliaceae have Axile placentation. Gram, Arhar, Sun hemp, Moon, Pea & Lupin belong to Fabaceae. Therefore answer is six. Tulip, Asparagus, Colchicine & onion belong to Liliaceae. Chilli and Tobacco belong to Solanaceae.

*300. Onion (Liliaceae) has valvate aestivation. Maize has both C_4 and C_3 pathway. Pea has non endospermic seeds. Tomato (Solanaceae) has valvate aestivation. Thus although Maize is a C_4 plant but C_3 pathway is present in all plants thus (b) becomes the only correct option.

*301. Walnut is a drupe and not a true nut. The outer green husk resembles the outer pericarp (epicarp&mesocarp) and is removed at the time of harvest. The hard shell surrounding the seed is endocarp. Seed is its edible part. Radish is lomantaceoussiliqua; apple is a pome; tomato is a berry and poppy is a porocidal capsule.

*303. *Sesbania* and *Trifolium* belong to the family Fabaceace (Leguminosae) which has racemose inflorescence.*Brassicaceae* family also has racemose inflorescence.

*308. *Trifolium* belongs to the family Fabaceae in which leaves are generally compound, usually trifoliate, modified partly or wholly into tendril with pulvinate leaf base. The other three plants belong to family Solanaceae.

*310. Among bitter gourd, mustard, brinjal, pumpkin, china rose, lupin, cucumber, sunnhemp, gram, guava, bean, chilli, plum, petunia, tomato, rose, withania, potato, onion, aloe and tulip how many plants have Hypogynous flower?
(1) Fifteen (2) Eighteen
(3) Six (4) Ten *(NEET 2013)*

311. Seed coat is not thin, membranous in
(1) Groundnut (2) Gram
(3) Maize (4) Coconut
(NEET 2013)

*312. Placenta and pericarp are both edible portions in
(1) Potato (2) Apple
(3) Banana (4) Tomato *(AIPMT 2014)*

*313. An example of edible underground stem is
(1) Potato (2) Carrot
(3) Groundnut (4) Sweet potato
(AIPMT 2014)

314. Which one of the following statements is correct?
(1) A sterile pistil is called a staminode.
(2) The seed in grasses is not endospermic
(3) Mango is a parthenocarpic fruit
(4) A proteinaceousaleurone layer is present in maize grain *(AIPMT 2014)*

315. An aggregate fruit is one which develops from
(1) Multicarpellary superior ovary
(2) Multicarpellary syncarpous gynoecium
(3) Multicarpellary apocarpus gynoecium
(4) Complete inflorescence *(AIPMT 2014)*

316. Non-albuminous seed is produced in
(1) Pea (2) Maize
(3) Castor (4) Wheat *(AIPMT 2014)*

317. Leaves become modified into spines in
(1) Pea (2) Onion
(3) Silk Cotton (4) *Opuntia*
(AIPMT 2015)

*318. $\oplus \, ⚥ \, K_{(5)} \, \overset{\curvearrowleft}{C_{(5)} \, A_5} \, G_{\underline{(2)}}$ is the floral formula of
(1) *Sesbania* (2) *Petunia*
(3) *Brassica* (4) *Allium*
(AIPMT 2015)

*319. Keel is the characteristic feature of flower of
(1) *Indigofera* (2) *Aloe*
(3) Tomato (4) Tulip
(AIPMT 2015)

*320. Perigynous flowers are found in
(1) Cucumber (2) China rose
(3) Rose (4) Guava
(AIPMT 2015)

321. Flowers are unisexual in
(1) Pea (2) Cucumber
(3) China rose (4) Onion
(AIPMT Retest 2015)

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*310. Fabaceae, Solanaceae; Brassicaceae; Malvaceae and Liliaceae all show hypogynous flower (*i.e.*, superior ovary).
1. Mustard (Brassicaceae) ; 2. Brinjal (Solanacae) ; 3. Chinarose (Malvaceae) ; 4. Lupin (Fabaceae)
5. Sunhemp (Fabaceae) ; 6. Gram (Fabaceae) ; 7. Bean (Fabaceae) ; 8. Chilli (Solanaceae)
9. Petunia (Solanaceae) ; 10. Tomato (Solanaceae) ; 11. Withania (Solanaceae) ; 12. Potato (Solanaceae)
13. Onion (Liliaceae) ; 14. Aloe (Liliaceae) ; 15. Tulip (Liliaceae)
- **Guava cucumber, Bitter gourd, Pumpkin have inferior ovary.**
- **Plum, Rose and Peach have half inferior ovary.**

*312. • Potato - modified stem ; • Apple - Thalamus is edible ; • Banana - Mesocarp and Endocarp is **edible**;
• Tomato - Pericarp and Placenta is **edible**.

*313. • Potato - edible underground stem ; • Carrot - edible underground root ; • Groundnut - edible part is seed; • Sweet potato - edible part is root.

*318. This is a floral formula of Solanaceae. *Sesbania* belongs to family Fabaceae, *Brassica* to Brassicaceae and *Allium* to Liliaceae.

*319. – 'Keel' is the feature of the flower of Leguminosae family.
– *Indigofera* belongs to Leguminosae.
– *Aloe* and Tulip belong to Liliaceae.
– Tomato belongs to Solanaceae.

*320. • Perigynous flower is seen in Rose, plum and peach.
• In cucumber and guava flower is epigynous.
• In China rose flower is hypogynous.

322. Roots play insignificant role in absorption of water in
(1) Sunflower (2) *Pistia*
(3) Pea (4) Wheat
(AIPMT Retest 2015)

*323. Axile placentation is present in
(1) *Dianthus* (2) Lemon
(3) Pea (4) *Argemone*
(AIPMT Retest 2015)

*324. Among China rose, mustard, brinjal, potato, guava, cucumber, onion and tulip, how many plants have superior ovary?
(1) Five (2) Six (3) Three (4) Four
(AIPMT Retest 2015)

325. Which one of the following fruits is parthenocarpic?
(1) Brinjal (2) Apple
(3) Jackfruit (4) Banana
(AIPMT Retest 2015)

326. Stems modified into flat green organs performing the functions of leaves are known as
(1) Phyllodes (2) Phylloclades
(3) Scales (4) Cladodes
(AIPMT/NEET 2016)

327. The standard petal of a papilionaceous corolla is *also* called
(1) Pappus (2) Vexillum
(3) Corona (4) Carina
(AIPMT/NEET 2016)

328. Tricarpellary, syncarpous gynoecium is found in flowers of
(1) Solanaceae (2) Fabaceae
(3) Poaceae (4) Liliaceae
(AIPMT/NEET 2016)

329. Cotyledon of maize grain is called
(1) Coleorhiza (2) Coleoptile
(3) Scutellum (4) Plumule
(AIPMT/NEET 2016)

330. Which of the following is not a stem modification?
(1) Thorns of citrus
(2) Tendrils of cucumber
(3) Flattened structures of *Opuntia*
(4) Pitcher of *Nepenthes*
(AIPMT/NEET 2016)

331. Proximal end of the filament of stamen is attached to the
(1) Connective (2) Placenta
(3) Thalamus or petal
(4) Anther
(AIPMT/NEET 2016)

332. The term 'polyadelphous' is related to
(1) gynoecium (2) androecium
(3) corolla (4) calyx
(NEET-2-2016)

*333. How many plants among *Indigofera*, *Sesbania*, *Salvia*, *Allium*, *Aloe*, mustard, groundnut, radish, gram and turnip have stamens with different lengths in their flowers?
(1) Three (2) Four
(3) Five (4) Six *(NEET-2-2016)*

*334. Radial symmetry is found in the flowers of
(1) *Brassica* (2) *Trifolium*
(3) *Pisum* (4) *Cassia*
(NEET-2-2016)

*335. Free-central placentation is found in
(1) *Dianthus* (2) *Argemone*
(3) *Brassica* (4) *Citrus*
(NEET-2-2016)

*336. Which one of the following statements is not correct?
(1) Offspring produced by the asexual reproduction are called clone.
(2) Microscopic, motile asexual reproductive structures are called zoospores
(3) In potato, banana and ginger, the plantlets arise from the internodes present in the modified stem.
(4) Water hyacinth, growing in the standing water, drains oxygen from water that leads to the death of fishes.
(NEET-2-2016)

337. Match Column – I with Column – II and select

*323. • Dianthus – Free central placentation • Lemon – Axile placentation
• Pea – Marginal placentation • Argemone – Parietal placentation

*324. China Rose; Mustard; Brinjal; Potato; Onion and Tulip (Total 6) have superior ovary. Guava and Cucumber have inferior ovary.

*333. *Salvia* has two pairs of stamens with each pair of different length. Mustard; Radish; Turnip belong to Brassicaceae family which shows tetradynamous condition (2 short; 4 long stamens).

*334. Trifolium; *Pisum* and *Cassia* belong to Fabaceae family, all three have zygomorphic flowers.

*335. *Argemone* and *Brassica* show Parietal placentation. *Citrus* shows Axile placentation.

*336. In option (c); the plantlets arise from the **nodes** present in modified stem.

the correct option using the codes given below

Column – I	Column – II
1. Pistils fused together	(i) Gametogenesis
2. Formation of gametes	(ii) Pistillate
3. Hyphae of higher Ascomycetes	(iii) Syncarpous
4. Unisexual female flower	(iv) Dikaryotic

Codes

	1	2	3	4
(1)	(iv)	(iii)	(i)	(ii)
(2)	(ii)	(i)	(iv)	(iii)
(3)	(i)	(ii)	(iv)	(iii)
(4)	(iii)	(i)	(iv)	(ii)

(NEET-2-2016)

338. In Bougainvillea thorns are the modifications of
(1) stipules (2) adventitious root
(3) stem (4) leaf *(NEET-2017)*

339. Coconut fruit is a
(1) Drupe (2) Berry
(3) Nut (4) Capsule
(NEET-2017)

340. The morphological nature of the edible part of coconut is
(1) perisperm (2) cotyledon
(3) endosperm (4) pericarp
(NEET-2017)

ANSWERS

1. (2)	2. (1)	3. (1)	4. (2)	5. (1)	6. (3)	7. (3)	8. (4)	9. (1)	10. (1)
11. (1)	12. (3)	13. (1)	14. (2)	15. (3)	16. (2)	17. (1)	18. (2)	19. (2)	20. (2)
21. (1)	22. (1)	23. (3)	24. (2)	25. (2)	26. (2)	27. (2)	28. (1)	29. (2)	30. (1)
31. (1)	32. (1)	33. (4)	34. (2)	35. (3)	36. (3)	37. (3)	38. (2)	39. (4)	40. (2)
41. (3)	42. (3)	43. (1)	44. (2)	45. (2)	46. (1)	47. (2)	48. (1)	49. (4)	50. (2)
51. (1)	52. (1)	53. (1)	54. (2)	55. (3)	56. (2)	57. (2)	58. (3)	59. (3)	60. (1)
61. (3)	62. (1)	63. (1)	64. (3)	65. (3)	66. (3)	67. (2)	68. (2)	69. (2)	70. (2)
71. (2)	72. (1)	73. (4)	74. (3)	75. (2)	76. (2)	77. (3)	78. (4)	79. (3)	80. (3)
81. (2)	82. (2)	83. (2)	84. (4)	85. (3)	86. (2)	87. (3)	88. (4)	89. (2)	90. (2)
91. (1)	92. (1)	93. (4)	94. (3)	95. (2)	96. (1)	97. (3)	98. (3)	99. (2)	100. (3)
101. (2)	102. (2)	103. (2)	104. (1)	105. (2)	106. (4)	107. (4)	108. (2)	109. (4)	110. (2)
111. (2)	112. (2)	113. (1)	114. (2)	115. (2)	116. (1)	117. (2)	118. (2)	119. (2)	120. (3)
121. (2)	122. (2)	123. (1)	124. (3)	125. (2)	126. (2)	127. (2)	128. (2)	129. (3)	130. (1)
131. (4)	132. (1)	133. (1)	134. (2)	135. (1)	136. (2)	137. (2)	138. (2)	139. (1)	140. (3)
141. (2)	142. (1)	143. (3)	144. (1)	145. (2)	146. (4)	147. (2)	148. (4)	149. (1)	150. (4)
151. (1)	152. (1)	153. (4)	154. (3)	155. (4)	156. (1)	157. (3)	158. (1)	159. (1)	160. (2)
161. (1)	162. (1)	163. (1)	164. (1)	165. (2)	166. (1)	167. (1)	168. (2)	169. (1)	170. (1)
171. (3)	172. (2)	173. (2)	174. (3)	175. (1)	176. (2)	177. (2)	178. (4)	179. (2)	180. (4)
181. (3)	182. (4)	183. (1)	184. (2)	185. (1)	186. (4)	187. (1)	188. (3)	189. (1)	190. (2)
191. (2)	192. (2)	193. (4)	194. (3)	195. (3)	196. (1)	197. (3)	198. (1)	199. (2)	200. (2)
201. (1)	202. (2)	203. (1)	204. (3)	205. (1)	206. (4)	207. (1)	208. (2)	209. (3)	210. (3)
211. (1)	212. (3)	213. (3)	214. (4)	215. (1)	216. (4)	217. (1)	218. (3)	219. (2)	220. (3)
221. (2)	222. (3)	223. (2)	224. (2)	225. (4)	226. (4)	227. (3)	228. (2)	229. (2)	230. (4)
231. (4)	232. (1)	233. (3)	234. (2)	235. (4)	236. (3)	237. (4)	238. (1)	239. (4)	240. (2)
241. (4)	242. (4)	243. (3)	244. (2)	245. (2)	246. (2)	247. (3)	248. (4)	249. (4)	250. (4)
251. (3)	252. (3)	253. (3)	254. (2)	255. (3)	256. (4)	257. (3)	258. (3)	259. (3)	260. (1)
261. (3)	262. (1)	263. (3)	264. (4)	265. (3)	266. (2)	267. (4)	268. (1)	269. (2)	270. (4)
271. (2)	272. (1)	273. (2)	274. (4)	275. (2)	276. (4)	277. (2)	278. (3)	279. (2)	280. (3)
281. (2)	282. (1)	283. (2)	284. (1)	285. (2)	286. (2)	287. (1)	288. (1)	289. (1)	290. (1)
291. (2)	292. (4)	293. (4)	294. (4)	295. (2)	296. (2)	297. (2)	298. (1)	299. (1)	300. (2)
301. (3)	302. (3)	303. (4)	304. (4)	305. (3)	306. (4)	307. (2)	308. (2)	309. (3)	310. (1)
311. (2)	312. (4)	313. (1)	314. (4)	315. (3)	316. (1)	317. (4)	318. (2)	319. (1)	320. (3)
321. (2)	322. (2)	323. (2)	324. (2)	325. (4)	326. (2)	327. (2)	328. (4)	329. (3)	330. (4)
331. (3)	332. (2)	333. (2)	334. (1)	335. (1)	336. (3)	337. (4)	338. (3)	339. (1)	340. (3)

6 ANATOMY OF PLANTS

Anatomy (Gk. *ana*– up, *tome*– cutting) is the study of internal structure of organisms. In plants, anatomy includes histology, that is, organisation and structure of tissues.

Importance of Anatomy

1. Anatomy or study of internal structure is useful in knowing the structural peculiarities of different groups of plants.
2. It indicates the structural adaptations of plants to diverse environments.
3. It provides information to functional organisation of higher plants.
4. Structural details of different organs in different groups of plants are known.
5. Anatomy is useful for knowing **homology** (phylogenetic similarity) and **analogy** (phylogenetic dissimilarity).
6. Anatomy has solved several taxonomic problems.
7. It is useful in determining the purity of articles of daily use like tea, coffee, cocoa, tobacco, vegetable dyes, spices, asafoetida, saffron, etc.
8. In **pharmacognosy** (science connected with sources, characteristics and possible medicinal uses) purity and correct identity of plant parts is established through anatomy.
9. Plywood industry depends upon the knowledge of wood anatomy.
10. Wood anatomy helps to differentiate the superior and inferior, standard and substandard or specified and unspecified woods.
11. Forensic science employs plant anatomy for identifying pieces of plant matter sticking to dead bodies and articles used by criminals.

TISSUES

A group of cells having a common origin and co-operating with one another to perform a similar function (or a set of similar functions) *is described as a tissue*. Plasmodesmata often occur amongst cells for proper coordination. Depending upon the constitution of cells, the tissues are of two types, **simple** and **complex**. A **simple tissue** is made up of **similar cells** which carry out the same function. A **complex tissue** is made up of **two** or **more than two** types of cells which are aggregated from the beginning and perform a similar function.

Based on the capacity to divide, the plant tissues have been classified into two fundamental types, **meristematic** and **permanent**.

Meristematic Tissues

A **meristem** or **meristematic tissue** (Gk. *meristos*— divided) is a simple tissue composed of a group of **similar** and **immature cells** (*meristematic cells*) which can **divide** and form **new cells.**

Characteristics of Meristematic Cells. (i) Ability to grow and divide. (ii) Small immature cells. (iii) Isodiametric, rounded, oval or polygonal. (iv) Absence of intercellular spaces.

(v) Walls are thin, elastic and made of cellulose. (vi) Nucleus conspicuous. (vii) Cytoplasm dense. (viii) Vacuoles absent or very small. (ix) Crystals absent. (x) Endoplasmic reticulum small. (xi) Proplastids are present instead of plastids. (xii) Mitochondria have simple structure. (xiii) Rate of respiration is very high. (xiv) There is large scale synthetic activity. (xv) There is little reserve food. (xvi) Cells of the cambium are, however, slightly different. They possess large vacuoles and are elongated.

Promeristem (Gk. *pro*— before, *meristos*–divided). It is part of apical meristem having actively dividing cells and their most recent derivatives.

Promeristem Derivatives. They differentiate into three regions. Hanstein (1870) has called them **histogens** (Gk. *histos*–tissue, *gennaein* — to produce). **Histogens** are tissue producing definite zones or regions. They are dermatogen, periblem and plerome.

(i) **Dermatogen**. (Gk. *derma*-skin, *genea*-birth). It is the region or histogen of single layer of outermost cells formed from the apical meristem. Dermatogen gives rise to epidermis of stem and other aerial parts. In root it gives rise to epiblema and root cap or **calyptrogen** (Gk. *kalyptra*–covering, *gennaein*–to produce). Calyptrogen is meristematic and forms root cap.

(ii) **Periblem** (Gk. *peri*–around, *blema*–covering). It is middle histogen which forms cortex of stem and roots.

(iii) **Plerome** (Gk. *pleroma*–a filling). It is the central histogen which forms stele or part of stem and root inner to endodermis. Part of plerome that forms vascular tissues is called procambium.

Haberlandt (1914) has proposed a different nomenclature of protoderm, ground meristem and procambium.

(a) **Protoderm** (Gk. *protos*–first, *derma*–skin). It is the outer layer of apical meristem that gives rise to epidermis of stem and epiblema of root.

(b) **Ground Meristem.** It is primary meristem formed from apical meristem which gives rise to ground tissues of the plant body. Ground tissues comprise all tissues except epidermis and vascular strands.

(c) **Procambium** (L. *pro*–before, *cambium*–change). It is part of meristem which gives rise to vascular tissues.

The meristematic cells are **parent cells** from which all other types of cells are formed. Depending upon their origin, meristems are of two types, **primary** and **secondary.**

1. **Primary Meristems**. They are those meristematic tissues which are derived directly from the meristems of the embryo. Depending upon their position, primary meristems are of three types : apical, intercalary and lateral (Fig. 6.1).

(a) **Apical Meristems**. The apical meristems are present at the tips of stem, root and their branches. They produce growth in length.

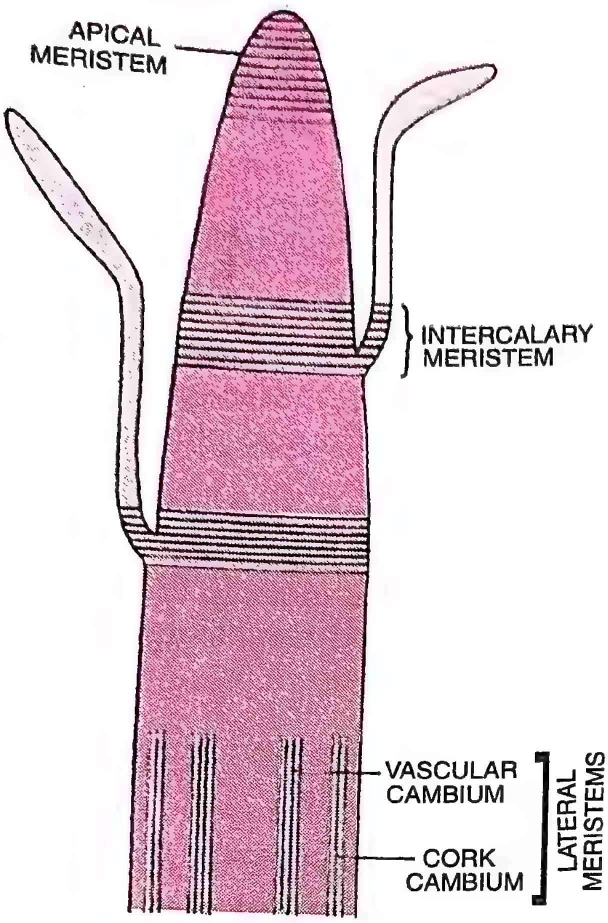


Fig. 6.1. Types of meristems.

Vegetative Shoot Apex (Shoot Apical Meristem). It is derived from meristem present in plumule of embryo. Shoot apex occurs at the tip of stem and its branches as **terminal bud.** It also occurs in the inactive state in the axils of leaves as **lateral buds.** Shoot apex is conical or dome-shaped in outline. It is covered over and protected

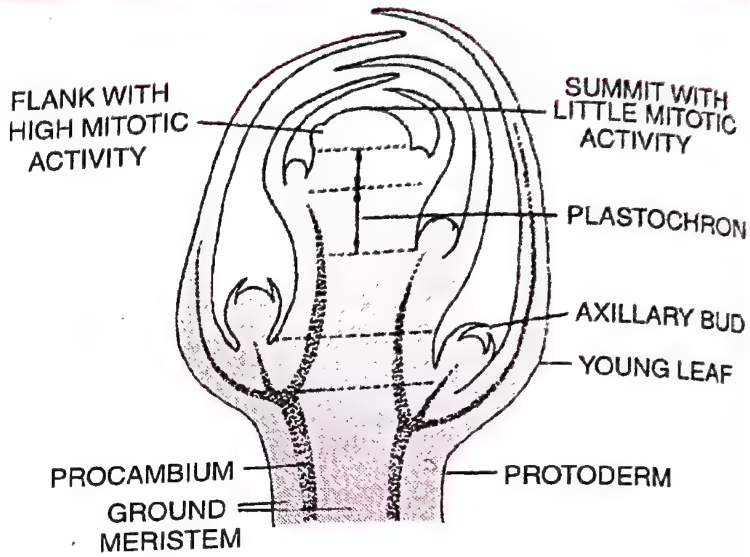


Fig. 6.2. L.S. Vegetative shoot apex showing regions of activity.

by means of young leaves formed by it. The meristem consists of a single apical cell in many pteridophytes. In seed plants the apical meristem is a dome-shaped mass of meristematic cells. Leaf primordia are produced periodically on the flanks. The period between the appearance of two successive leaf primordia is called **plastochron** (= plastochrone, Fig. 6.2). Part of stem consisting of a node, leaf, axillary bud and internode is called **phytomer.** During a plastochron the shoot apex goes through a cycle of changes. It gives rise to derivatives in the basal region as well. They add new tissues and cause elongation of shoot.

Some cells of shoot apical meristem are left behind during the formation of leaves and elongation of the stem. They consititue **axillary buds.**

Derivatives of apical meristem produce the **primary plant body.** Specific regions of apical meristem give rise to specific tissues-dermal, ground and vascular. According to **tunica-corpus** theory of Schmidt (1924), the shoot apex has two parts, outer mantle like **tunica** and inner cellular mass known as **corpus** (Fig. 6.3). Cells of tunica are small. They undergo anticlinal divisions and form surface meristem called **protoderm.** Protoderm gives rise to epidermis of both stem as well as leaves. If tunica is more than one layer in thickness, the outer layer differentiates into protoderm while the inner layers contribute to the formation of leaf interior and cortical tissues.

Cells of corpus are comparatively larger. They divide in different planes. Cells derived from corpus form procambium and ground meristem. **Procambium** is slow to differentiate. Initially its cells are narrow, elongated and densely cytoplasmic. They occur in parallel files.

Procambium gives rise to primary phloem, primary xylem and intrafascicular cambium between the two (in case of dicots and gymnosperms). **Ground meristem** differentiates into pith in the centre and pericycle, endodermis, cortex and hypodermis respectively towards the outer side.

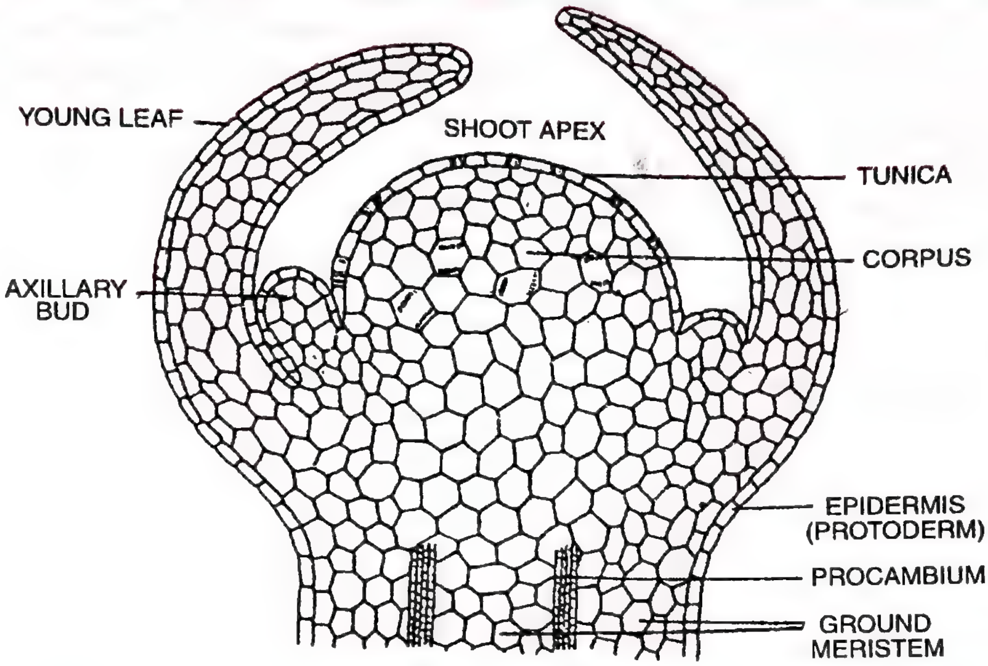


Fig. 6.3. Longitudinal section of a vegetative shoot apex.

According to **histogen theory** of Hanstein (Hanstein, 1870), the stem apical meristem is differentiated into three regions or histogens (Fig. 6.4) — **dermatogen** (forms epidermis), **periblem** (forms cortex and endodermis) and **plerome** (forms pericycle, vascular bundles, medullary rays and pith). Histologically vegetative **shoot apical meristem** or **SAM** consists of three components — central zone (CZ), peripheral zone (PZ) and **rib zone** (RZ).

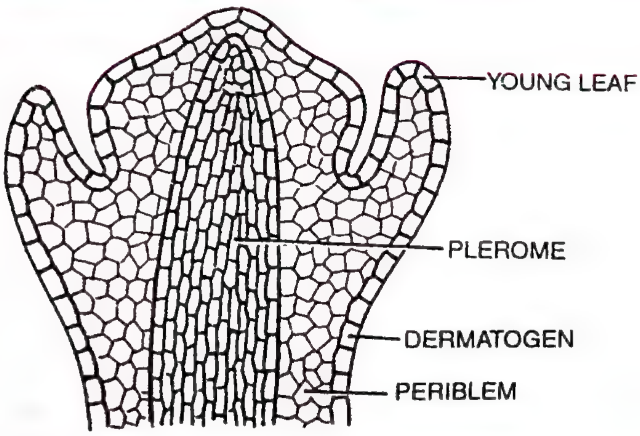


Fig. 6.4. L.S. Vegetative shoot apex showing histogens.

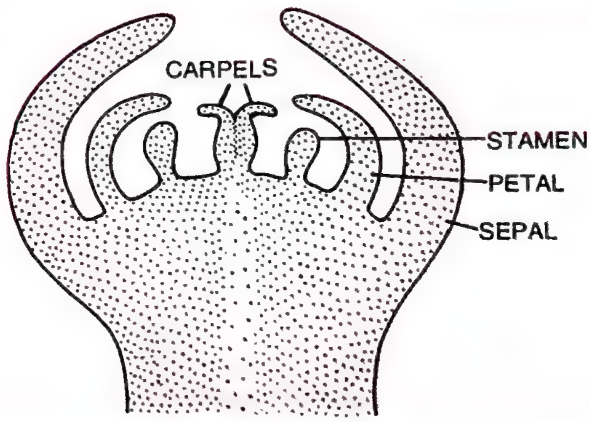


Fig. 6.5. L.S. Reproductive apex (diagrammatic).

Reproductive Shoot Apex (Fig. 6.5) During reproductive phase all or some of shoot apices get changed into reproductive apices. The shoot apex stops producing new leaf primordia and axillary buds on the flanks. The cyclicity of divisions comes to an end. The meristem broadens, becomes less conical and increases in size. The summit cells, which

were quite inactive in the vegetative shoot apex, begin to divide actively. Therefore, all parts of the reproductive shoot apex show meristematic activity. It may give rise to an inflorescence or a single flower. When a single flower is to be formed, the meristematic cells give rise to different floral parts in the different regions. The meristematic cells get depleted or consumed in the formation of the various floral parts. So further growth stops. The different floral parts formed by reproductive apex from below to tip or outside to the centre are sepals, petals, stamens and carpels. Sepal primordia are the first to be formed. They come to lie at the lower end while other floral organs are formed successively higher up (exceptions found in some perigynous and epigynous flowers). Sepals enlarge rapidly and come to surround and protect the remaining floral organs. Carpels are the last to be formed. During their formation the apex of the meristem is used up.

Differences between Vegetative and Reproductive Shoot Apices

Vegetative Shoot Apex	*Reproductive Shoot Apex*
1. It is conical in outline.	1. Reproductive shoot apex is comparatively flattened.
2. The apex is narrow.	2. It is wide.
3. It is protected by young leaves.	3. Reproductive shoot apex is generally protected by sepals.
4. Vegetative shoot apex gives rise to various parts in a cyclic manner.	4. The sequence of formation of different parts is not repeated.
5. It gives rise to leaves, buds and stem tissues.	5. It forms sepals, petals, stamens and carpels besides the internal stem tissues.
6. Vegetative shoot apex gives rise to normal leaves.	6. Normal leaves are absent though small specialized leaves called bracts can be formed.
7. Internodes are of equal length.	7. The first internode is usually very long and forms the pedicel. The other internodes are short and commonly indistinguishable. As a result the various floral whorls develop close together.
8. Lateral appendages are generally borne in spirals.	8. Lateral appendages generally develop in whorls.
9. The summit of the vegetative shoot apex is comparatively inactive.	9. The summit of the reproductive shoot apex shows active divisions.
10. Vegetative shoot apex shows indefinite growth.	10. Growth of the reproductive apex is definite or determinate.
11. The meristem is not consumed in the formation of vegetative organs.	11. The reproductive shoot apex gets consumed in the formation of reproductive organs.

Root Apex (Root Apical Meristem). It is found at the tip of main root and its branches. In case of tap root system, the root apical meristem is formed from radicle part of the embryo or its derivative. In adventitious roots, the root apical meristem is produced from derivatives of shoot apex.

Root apical meristem (Fig. 6.6) is subterminal because it is covered by root cap. It does not produce lateral appendages. Root branches develop much behind the apex from the interior of the root (endogenous origin). In many cases, a **quiescent centre** (Clowes, 1961) is found in the centre of the root apex. Cell divisions are very few in the quiescent centre

as there is very little synthesis of new proteins, RNAs and DNA. Quiescent centre may function as reserve meristem. Due to presence of quiescent centre, the root apical meristem appears cup–shaped or hemispherical. Differential divisions in various parts of root apical meristem gives rise to 3–4 regions—**protoderm, procambium, ground meristem** and **calyptrogen.** Calyptrogen differentiates only in monocots. It gives rise to root cap. Protoderm forms epiblema or epidermis. In dicots it also produces root cap. Procambium gives rise to vascular tissues. Ground meristem forms pith (if present), endodermis and cortex.

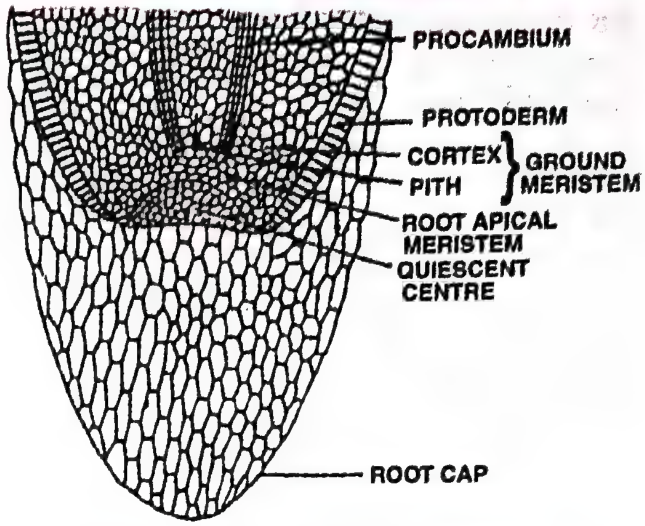


Fig. 6.6. L.S. Root Apical Meristem.

Differences between Shoot Apex and Root Apex

Shoot Apex	*Root Apex*
Position	
1. It is truely terminal.	1. Root apex is actually subterminal.
Structure	
2. Shoot apex is comparatively long and spread over a distance of over 1 cm.	2. It is quite short, less than 1 mm in length.
3. It is dome-shaped in outline.	3. Root apex is generally cup-shaped in outline.
4. A quiescent centre is not distinguishable.	4. A quiescent centre occurs in many root apices.
5. Shoot apex is covered by juvenile leaves.	5. Root apex is protected by a root cap.
Function	
6. New cells are added only towards the base.	6. New cells are added both towards the base and apex.
7. It produces alternate bands of nodes and internodes.	7. Nodes and internodes are not formed.
8. It gives rise to lateral appendages in the form of leaves.	8. Lateral appendages are not produced by the root apex.
9. Primordia of the branches develop in the axils of leaves in the region of apex.	9. Primordia of branches develop far behind the root apex.
10. Branches arise exogenously.	10. Branches develop endogenously.
11. Plastochrons or periodic cyclic changes occur on the flanks of the shoot apex.	11. They are not distinguishable in the root apex.
12. Shoot apex changes its activity during reproductive phase.	12. No change occurs during reproductive phase.
13. The organization of shoot apex can be explained on the basis of tunica corpus theory.	13. The organisation of root apex can be explained on the basis of histogen theory.
14. Demarcation of the different regions of the meristem and its derivatives is not elaborate.	14. There is a high degree of differentiation in the meristem and its derivatives.

Histogen theory of Hanstein (1870) believes root apex to have three regions or histogens— **dermatogen** (forms epiblema and root cap in dicots), **periblem** (forms cortex and endodermis) and **plerome** (forms pericycle, vascular strand and pith, if any).

Histological root apical meristem (RAM) consists of five parts — quiescent centre, columella initials (for central part of root cap), dermatocalyptrogen (for epiblema and root cap outer cells), cortical endodermal initals (periblem) and stele initials.

(b) **Intercalary Meristems**. They are meristematic regions which are derived from the apical meristems and which have been separated from them by the formation of permanent tissues in between. Intercalary meristems help in elongation of the organs. They also allow the fallen stems of cereals to become erect. Intercalary meristems are commonly found at the bases of leaves, above the nodes (*e.g.*, grasses) or below the nodes (*e.g.*, mint). The intercalary meristem present at the base of *Pinus* leaf (basal meristem) lives almost throughout the life of the leaf. Usually the intercalary meristems differ from other meristems in that they ultimately get fully used up in the formation of permanent tissues.

(c) **Lateral Meristem**. The meristem occurs on the sides and takes part in increasing girth of the plant. Only one type of primary lateral meristem is found in plants. It is **intrafascicular cambium**. The cambium lies in vascular bundles of dicot and gymnosperm stems in between phloem and xylem.

2. **Secondary Meristems**. The meristems are formed secondarily from the permanent tissues. Here, some of the permanent cells acquire the power of division. The phenomenon is called **dedifferentiation**. The secondary meristems are usually lateral. They are **cylindrical meristems.** The meristems give rise to secondary tissues that constitute secondary growth. The common examples are **vascular cambium** of the root (derived from conjunctive parenchyma), **interfascicular vascular cambium** of stem (formed from medullary ray cells), **cork cambium or phellogen** (from an outer layer of cortex), **wound cambium** (from the cells surrounding an area of injury or wound) and **accessory cambia** of monocots (*e.g.*, *Dracaena, Yucca*).

Differences between Primary and Secondary Meristems

Primary Meristem	*Secondary Meristem*
1. It is present from the beginning.	1. Secondary meristem is formed later in the life.
2. It develops from another meristem.	2. Secondary meristem develops from the permanent cells due to dedifferentiation.
3. The cells are usually isodiametric (exception intrafascicular cambium).	3. The cells are commonly elongated.
4. Central vacuoles are absent (exception intrafascicular cambium).	4. The cells possess central vacuoles.
5. It usually gives rise to primary tissues (exception intrafascicular cambium) that constitute primary growth.	5. Secondary meristem gives rise to secondary or supplementary tissues that constitute secondary growth. Secondary tissues either supplement or replace the primary tissues.
6. It usually produces growth in length (exception intrafascicular cambium).	6. Secondary meristem produces growth in thickness.

Differences between Plant Growth and Animal Growth

Plant Growth	*Animal Growth*
1. Plants possess well defined growing points or meristems.	1. Growing points or meristems are absent.
2. Growth is apical, intercalary or lateral.	2. Growth is diffused.
3. Growth is indefinite or unlimited.	3. Growth is definite or limited.
4. Plant growth continues throughout the life of a plant.	4. Growth stops in animals as soon as they mature, long before the appearance of senesence.
5. New organs continue to be formed throughout the life of a plant.	5. All organs are formed in the embryo. Later on, no new organs are added.
6. Old organs are replaced by new organs.	6. There is no such replacement.

Permanent Tissues

They are those tissues, the cells of which have lost the capacity to divide and have attained a permanent shape, size and function due to morphological, biochemical and physiological differentiation. Depending upon their origin, permanent tissues are of two types, **primary** (derived from apical and intercalary meristem) and **secondary** (derived from a lateral meristem). On the basis of composition, permanent tissues can be simple, complex and special (*e.g.*, secretory).

Simple Permanent Tissues

A simple permanent tissue is that tissue which is made up of similar permanent cells that carry out the same function or similar set of functions. Simple permanent tissues are of three types— parenchyma, collenchyma and sclerenchyma.

Parenchyma

(Gk. *para*– beside, *engchyma*– tissue)

Parenchyma is a simple permanent living tissue which is made up of thin-walled similar isodiametric cells. It is the **most abundant** and common tissue of plants. Typically the cells are isodiametric (all sides equal). They may be oval, rounded or polygonal in outline. The cell wall is made up of **cellulose**. Cells may be closely packed or have small intercellular spaces for exchange of gases (Fig. 6.7 B). Internally each cell encloses a large central vacuole and a peripheral cytoplasm containing nucleus. The adjacent parenchyma cells are connected with one another by plasmodesmata. They, therefore, form symplasm or living continuum.

Parenchyma is morphologically and physiologically unspecialised tissue that forms the ground tissue in the non-woody or soft areas of the stems, leaves, roots, flowers, fruits, etc. The typical parenchyma is meant for the storage of food, slow conduction of various substances and for providing turgidity to the softer parts of the plants. It is modified variously to perform special functions.

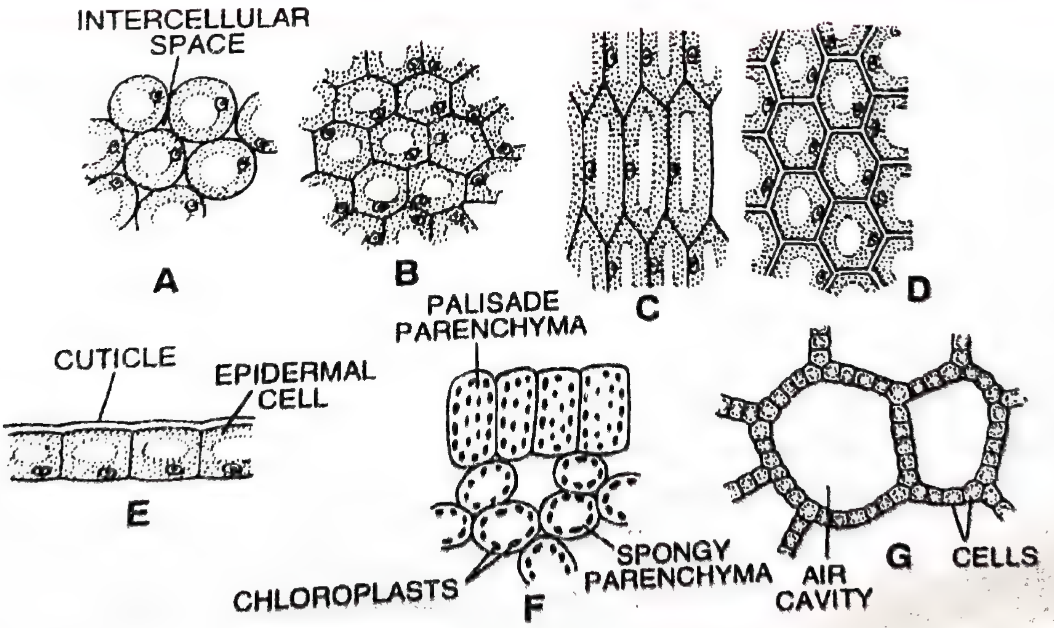


Fig. 6.7. Types of Parenchyma Cells. A–B, normal parenchyma cells; A, rounded; B, angular; C, prosenchyma; D, xylem parenchyma; E, epidermal cells; F, mesophyll; G, aerenchyma.

(a) Fibre-like elongated parenchyma is called **prosenchyma**. It is slightly thick walled and is meant for providing rigidity and strength.

(b) Cutinised parenchymatous cells form a protective covering layer or **epidermis**. Epidermis is single layered. Intercellular spaces are absent. The cutin also forms a distinct layer on the outer surface of epidermal cells. It is called **cuticle** (Fig. 6.7 E). It reduces transpiration.

(c) The young parts of the root are covered by a layer of unthickened and uncutinised parenchyma cells, some of which give rise to tubular outgrowths called root hairs. It is known as piliferous layer or **epiblema**. This layer is specialized to absorb water and mineral salts from the soil.

(d) **Xylem parenchyma** is made of small and often thickened cells. It helps in the storage of food and lateral conduction of water (Fig. 6.7 D).

(e) **Phloem parenchyma** is formed of thin-walled elongated parenchymatous cells. It takes part both in the storage and lateral conduction of food.

(f) Parenchyma cells containing chloroplasts are collectively termed as **chlorenchyma**. It takes part in the manufacture of food. Chlorenchyma of leaves is called **mesophyll**. It is differentiated into two parts, **palisade parenchyma** and **spongy parenchyma** (Fig. 6.7 F). Cells of palisade parenchyma are columnar in shape while those of spongy parenchyma are often lobed, rounded or irregular in outline.

(g) A special parenchyma tissue is found in the aquatic plants and some land plants (*e.g.*, petiole of Banana, *Canna*). It is known as **aerenchyma** (Fig. 6.7 G). It consists of a network of parenchyma cells which enclose very large **air cavities**. These air cavities store gases and make the aquatic plants light and bouyant.

Differences between Chlorenchyma and Aerenchyma

Chlorenchyma	*Aerenchyma*
1. It is parenchyma containing chloroplasts.	1. It is parenchyma containing air cavities.
2. The cells are large.	2. The cells are small.
3. It performs photosynthesis.	3. It provides buoyancy.
4. It is found in both aquatic and terrestrial plants.	4. It is found in aquatic plants.

(h) **Storage parenchyma** is made of large sized vacuolate cells which store water, mucilage and food, *e.g.*, *Aloe, Opuntia* Potato tuber.

(i) **Idioblasts** are specialized nongreen large-sized parenchyma cells which possess inclusions or ingredients like tannins, oils, crystals, etc.

(j) **Secretory cells** are specialized parenchyma cells that produce nectar, oil, etc.

Functions. (i) Storage of food. (ii) Providing turgidity to softer parts. (iii) Providing rigidity to tissues when prosenchymatous. (iv) Protection and checking water loss in the form of epidermis. (v) Formation of water absorbing epiblema in root. (iv) Lateral conduction in the form of xylem and phloem parenchyma (vii) Photosynthesis in the form of chlorenchyma. (viii) Providing buoyancy and storage of metabolic gases in the form of aerenchyma. (ix) Secretion.

Collenchyma

(Gk. *kolla*– glue, *enchyma*– tissue)

Collenchyma is a simple permanent tissue of refractile nonlignified living cells which possess pectocellulose thickenings in specific areas of their walls. The cells appear conspicu-

ous under the microscope due to their higher refractive index. The cells are often elongated. They are circular, oval or angular in transverse section. Internally each cell possesses a large central vacuole and a peripheral cytoplasm. Chloroplasts are often present. Wall possesses uneven longitudinal thickenings in specific areas. Depending upon the thickening, collenchyma is of three types : (i) **Angular Collenchyma.** The thickenings are present at the angles (angular thickenings), *e.g.*, stem of Tagetes, stem of Tomato (Fig. 6.8 B). (ii) **Lamellate Collenchyma.** The thickenings occur on the tangential walls (plate thickenings), *e.g.*, stem of Sunflower (Fig. 6.8 A). (iii) **Lacunate Collenchyma.** The thickenings are found on the walls bordering intercellular spaces (lacunate thickenings), *e.g.*, *Cucurbita* stem (Fig. 6.8 C).

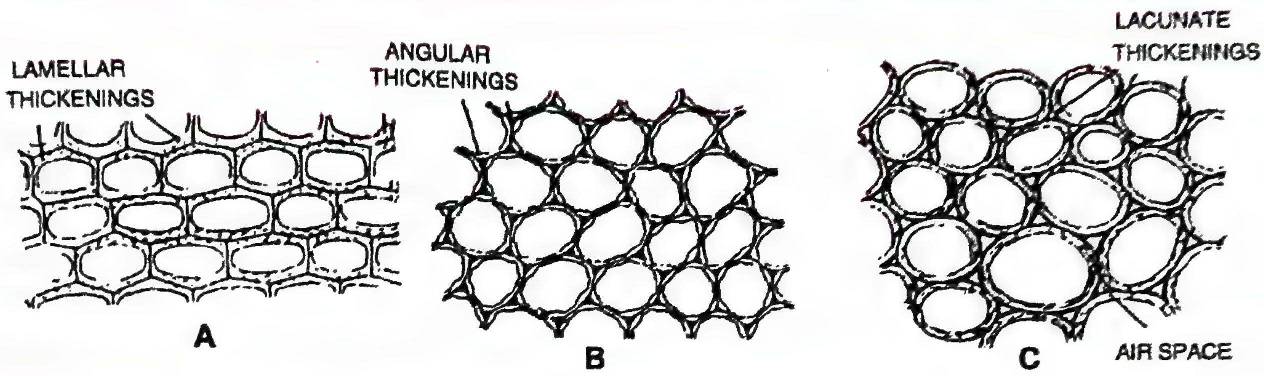


Fig. 6.8. Types of collenchyma (in T.S.). A, lamellate (plate type); B, angular; C, lacunate.

Collenchyma is found below the epidermis in the **petiole, leaves** and **stems of herbaceous dicots,** forming either continuous layers or occurring in patches, especially **in the** region of ridges (*e.g.*, Gourd).

Functions. (i) It provides mechanical strength to young dicot stems, petioles and leaves. (ii) While providing mechanical strength, collenchyma also provides flexibility to the organs and allows their bending, *e.g.*, *Cucurbita* stems. (iii) It prevents tearing of leaves. (iv) Collenchyma allows growth and elongation of organs. (v) Being living, its cells store food. (vi) Its cells often contain chloroplasts and take part in photosynthesis.

Differences between Parenchyma and Collenchyma

Parenchyma	*Collenchyma*
1. The cell wall is commonly thin but uniform in thickness.	1. The cell walls develop extra thickenings at places (tangential walls, angles or adjacent to intercellular spaces).
2. It provides mechanical strength only when the cells are fully turgid.	2. Collenchyma is a living mechanical tissue.
3. Parenchyma is found in both the outer and inner parts of plant organs.	3. Collenchyma is mostly restricted to the subepidermal parts of aerial plant organs.
4. It does not have a high refractive index.	4. It usually has high refractive index.
5. It shows several types of modifications.	5. Modifications are very few.
6. It occurs in both primary and secondary structures of plants.	6. It occurs in only aerial primary body parts of the plants.
7. It has the ability to dedifferentiate and form secondary meristem.	7. The ability to dedifferentiate is nearly absent.

Sclerenchyma

(Gk. *scleros*— hard, *enchyma*— tissue)

Sclerenchyma is a simple supportive tissue of **highly** thick-walled cells with little or no protoplasm. The cell cavities are narrow. The thickening of the wall may be made up of **cellulose** or **lignin** or **both**. A few to numerous pits occur in the wall. Sclerenchyma is of two types, **sclerenchyma fibres** and **sclereids**.

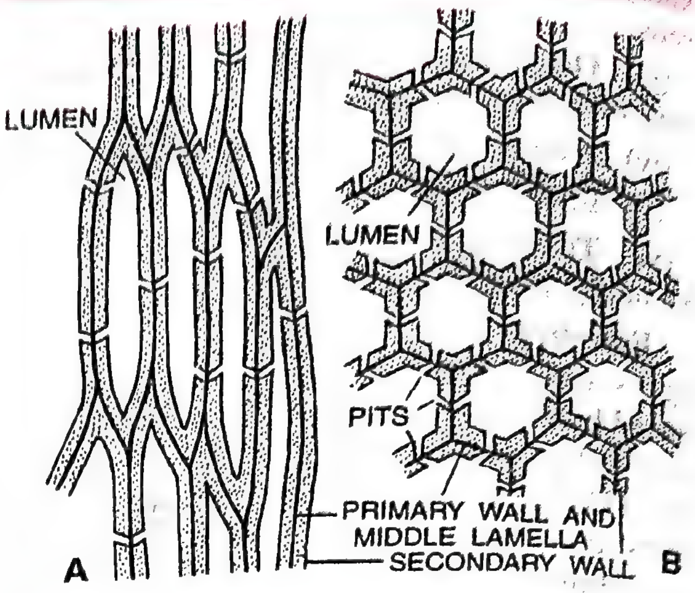


Fig. 6.9. Sclerenchyma Fibres. A, longitudinal section; B, transverse section.

(a) **Sclerenchyma Fibres***. The sclerenchyma fibres are highly elongated (1–90 cm), narrow and spindle-shaped thick-walled cells with pointed or oblique end walls. The fibres generally occur in longitudinal bundles (Fig. 6.9A) where the pointed ends of adjacent fibres get interlocked to form a strengthening tissue. The adjacent fibres possess simple oblique pits (unthickened areas with common pit membranes). Bordered pits also occur in some fibres. Pits do not perform any function in the mature fibres since the latter are empty and dead.

Living firbes occur in *Tamarix aphylla*. They possess nucleated protoplasts for several years. Fibres are septate in phloem of Grape Vine.

Sclerenchyma fibres constitute the major mechanical tissue of the plants because they can bear compression, pull, bending and shearing. The fibres occur in all those parts where mechanical strength is required, viz., leaves, petioles, cortex, pericycle, phloem, xylem and around vascular bundles (*e.g.,* monocot stem). Commercial fibres obtained from plants are usually sclerenchyma fibres, *e.g.,* Jute, Flax, Hemp.

(b) **Sclereids**. They are highly thickened dead sclerenchyma cells with very narrow cavities. Sclereids are broader as compared to the fibres being isodiametric polyhedral, spherical, oval short or cylindrical. They may also be branched. The thick cell walls have branched or unbranched simple pits (Fig. 6.10). Being elongated, the pits of sclereids are also known as **pit canals**.

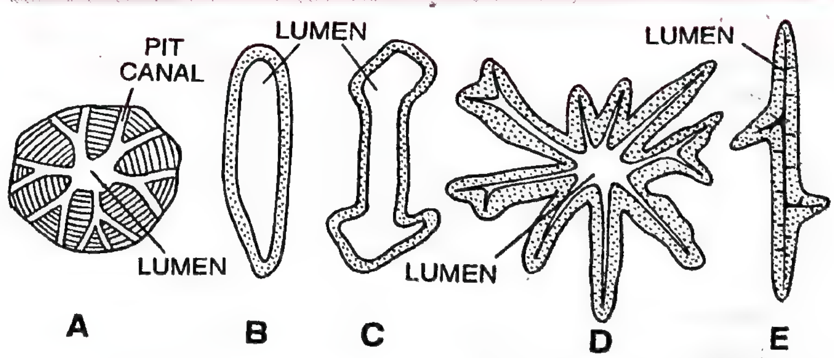


Fig. 6.10. Types of Sclereids. A, stone cell, (branchysclereid) with pit canals; B, macrosclereid; C, osteosclereid; D, astrosclereid; E, filiform sclereid.

Sclereids may occur singly or in groups. They provide **stiffness** to the parts in which they occur. The important types of sclereids are as follows :

(i) **Stone Cells or Brachysclereids**. Unbranched, short and isodiametric with ramiform (branched) pits, *e.g.*, grit of Guava, Sapota, Apple and Pear.

* Cotton fibres are not sclerenchyma fibres but unicellular epidermal hair with secondary wall thickening of cellulose.

(ii) **Macrosclereids.** Elongated and columnar or rod-like, *e.g.*, epidermal covering of legume seeds.

(iii) **Osteosclereids.** Bone-like or columnar with swollen ends, *e.g.*, sub-epidermal covering of some legume seeds.

(iv) **Astrosclereids.** Branched like a star, *e.g.*, tea leaves, petiole of Lotus.

(v) **Filiform Sclereids.** Fibre-like, sparingly branched, *e.g.*, *Olea*.

(vi) **Trichosclereids.** Very elongated hair-like and regularly once branched sclereids extending into intercellular spaces.

Functions. (i) Sclerenchyma is the chief mechanical tissue of the mature plant organs. (ii) It allows the plant organs to tolerate bending, shearing, compression and pull caused by environmental factors like wind. (iii) It provides rigidity to leaves and prevents their collapsing during temporary wilting. (iv) Sclereids provide strength to seed coverings. (v) Dehiscence of many fruits is based on differential distribution of sclerenchyma fibres, *e.g.*, pods. (vi) Sclereids form stony endocarp of many fruits called stone fruits, *e.g.*, Almond, Coconut. (vii) A number of fibres are commercially exploited, *e.g.*, Jute (*Corchorus*), Flax (*Linum*), Hemp (*Cannabis*).

Differences between Collenchyma and Sclerenchyma

Collenchyma	*Sclerenchyma*
1. It is made up of living cells.	1. Sclerenchyma cells are generally dead.
2. The cells are filled up with protoplasm.	2. The cells are empty.
3. Wall thickening is not uniform.	3. Wall thickening is uniform.
4. Wall thickening consists of cellulose.	4. Wall thickening can be of cellulose lignin or both.
5. Lumen or cell cavity is wide.	5. Lumen or cell cavity is usually narrow.
6. Pits are simple and straight.	6. Pits are usually simple and oblique. They may be branched.
7. Collenchyma provides mechanical strength as well as elasticity.	7. It is only a mechanical tissue.
8. It allows plant organs to stretch and elongate.	8. Sclerenchyma occurs in areas which have stopped elongation.
9. It keeps the organ soft.	9. It provides hardness to the region where it occurs.
10. Collenchyma has a high refractive index.	10. Refractive index is comparatively low.
11. Being living the cells can store food and take part in photosynthesis.	11. Sclerenchyma has no such function.

Differences between Fibres and Sclereids

Fibre	*Sclereid*
1. Elongated and narrow like a thread.	1. Usually broad.
2. End walls are tapering.	2. End walls are blunt in unbranched sclereids.
3. Fibres generally occur in bundles.	3. Sclereids occur singly or in loose groups.
4. Usually unbranched.	4. May be branched.
5. Pits narrow and unbranched.	5. Pits deep and commonly branched.
6. Pits are oblique.	6. Pits are straight.
7. Fibres are formed directly from derivatives of meristematic cells.	7. Sclereids arise by secondary thickening of parenchyma cells.
8. Fibres provide mechanical strength.	8. Sclereids provide stiffness only.

Complex Permanent Tissues

They are permanent tissues which contain more than one type of cells. All the types of cells of a complex tissue **work** as a unit. The common complex permanent tissues are **conducting tissues**, phloem and xylem.

Differences between Meristematic and Permanent Tissues

Meristematic Tissue	*Permanent Tissue*
1. It is a simple tissue.	1. It can be simple or complex.
2. The cells are small and isodiametric.	2. The cells are large and of different shapes according to the type of tissue.
3. Vacuoles are either small or absent.	3. Living cells of permanent tissues usually possess central vacuole.
4. Crystals and other cell inclusions are absent.	4. Crystals and other cell inclusions are often present.
5. Respiratory and biosynthetic activities are very high.	5. Both of them are at low level.
6. Intercellular spaces are very small or absent.	6. Intercellular spaces are often conspicuous.
7. The cell walls are thin.	7. The cell walls are thin or thick.
8. The cells have the property to undergo division.	8. The cells cannot normally divide.
9. The cells are immature.	9. The cells are fully differentiated.
10. Mitochondria are simple.	10. Mitochondria are fully developed.
11. Plastids are represented by proplastids.	11. Plastids are present in the living permanent cells.

Phloem

(Gk. *phlois*– inner bark; Nageli 1858)

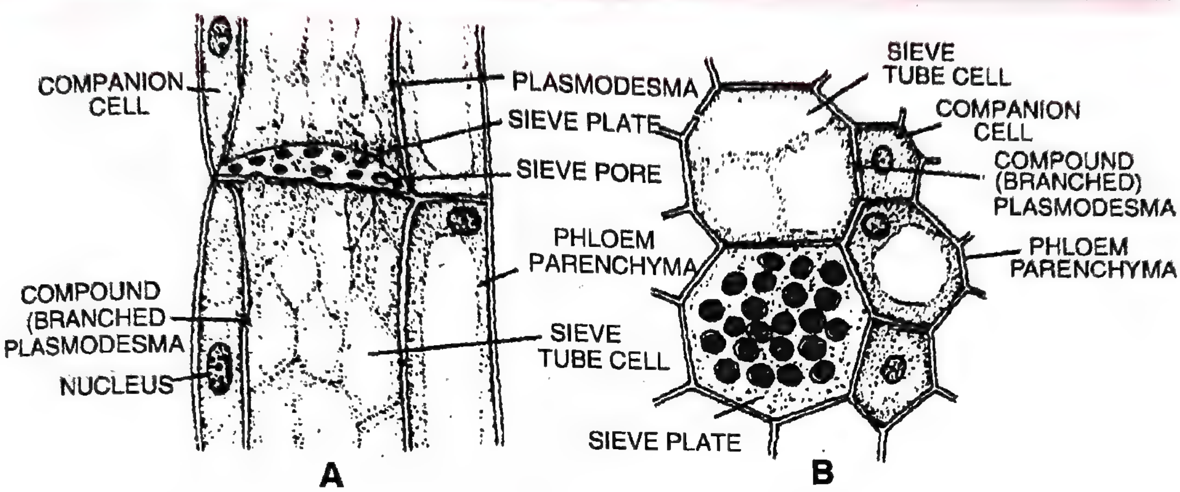
It is a complex tissue which **transports organic food** inside the body of the plant. Phloem is also called **bast** (= bass, a vague term). It consists of **four** types of cells, viz., **sieve tubes, companion cells, phloem parenchyma** and **fibres**. Haberlandt (1914) uses the term **leptom(e)** for the conducting part of phloem.

(a) **Sieve Tubes**. Sieve tubes are elongated tubular conducting channels of phloem. Each sieve tube is formed of several cells called **sieve tube elements** or **members**, sieve tube cells or **sieve elements**. Sieve tube members are placed end to end. The end walls are generally bulged out. They may be transverse or oblique. They have many small **pores** or **sieve pits**. Due to the presence of sieve pits the end walls are commonly called **sieve plates** (Fig. 6.11 A). In some cases the end walls of sieve elements possess more than one porous area. Such an end wall is called **compound sieve plate**, *e.g.*, Grape Vine, *Euphorbia royleana*. The sieve plates connect the protoplasts of **adjacent sieve tube members.**

In non-flowering plants sieve cells remain separate. They are narrower but more elongated as compared to individual sieve tube members. The end walls are oblique. Porous areas are less conspicuous. They are borne on the lateral walls of the elongated sieve cells. They are called **sieve areas.**

Internally a sieve tube member or cell has peripheral layer of cytoplasm without any nucleus (Fig. 6.11 A). The nucleus is, however, present in the young cells. The central part is occupied by a network of canals which contain fibrils of *p*-protein. Sieve tube takes part in the **conduction of organic food.**

(b) **Companion Cells.** Companion cells are narrow, elongated and thin walled **living cells.** They lie on the **sides** of the sieve tubes and are closely associated with them through **compound plasmodesmata.** They are squarish or rectangular in a transverse section. The cells have dense cytoplasm and a prominent nucleus. It is supposed that the nuclei of the companion cells control the activities of the sieve tube through plasmodesmata (Fig. 6.11). Companion cells also help in maintaining a proper **pressure gradient** in the sieve tube elements. Sieve tube member and its adjacent companion cells are derived from the same mother cell. Death of one results in death of the other as well. Companion cells are replaced by modified parenchyma cells (**albuminous cells**) in nonflowering plants.



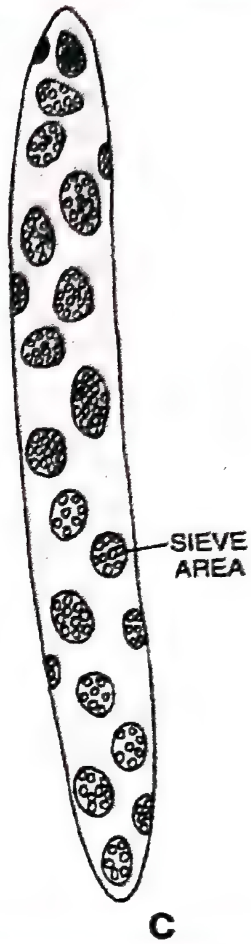


Fig. 6.11. Phloem. A, longitudinal section of phloem showing sieve tube, companion cells and phloem parenchyma cells; B, transverse section of a phloem showing sieve tube cells, companion cells and phloem parenchym cells. C, a sieve cell.

(c) **Phloem Parenchyma.** They are ordinary **living elongated** parenchyma cells having abundant plasmodesmata. They **store food**, resins, latex, mucilage, etc. The cells help in slow conduction of food, especially to the sides. Phloem parenchyma is **absent in most** of the monocots and some herbaceous dicots.

(d) **Phloem or Bast Fibres.** Sclerenchyma fibres found in the phloem are called **phloem** or **bast fibres.** They are generally absent in primary phloem but are quite common in secondary phloem where they occur more abundant in secondary phloem as compared to primary phloem. The fibres occur in sheets or cylinders. Phloem fibres provide **mechanical** strength. The textile fibres of flax, (*Linum usitatissimum*), hemp (*Cannabis*) and jute (Corchorus species) are phloem fibres.

Differences between Sieve Tube Member and Sieve Cell

Sieve Tube Member	*Sieve Cell*
1. It is a component of a long distance channel or sieve tube.	1. Sieve cell is an independently functioning entity.
2. Sieve tube members are usually associated with companion cells.	2. Companion cells are absent. Sieve cells may be associated with albuminous cells.

3. Companion cells and sieve tube elements are **sister cells** *i.e.*, derived from same mother cells.	3. Albuminous and sieve cells are derived from different mother cells.
4. The end wall is broad.	4. The end wall is pointed.
5. The pores are comparatively larger and fewer.	5. The pores are smaller but more numerous.
6. The pores or sieve pores are restricted to transverse end walls.	6. The sieve pores are found on both end walls as well as lateral walls.
7. Sieve pores generally form a single group on the sieve plate.	7. Sieve pores occur in many groups or sieve areas.
8. Sieve tube members or elements occur in flowering plants.	8. Sieve cells are found in nonflowering vascular plants (gymnosperms and pteridophytes).
9. Sieve tube elements are comparatively shorter and broader.	9. Sieve cells are comparatively narrower and longer.

Xylem

(Gk. *xylon*– wood; Nageli, 1858)

Xylem is a complex tissue which performs the function of **transport of water** or **sap** inside the plant. Simultaneously, it also provides **mechanical strength**. Xylem is also known as **wood**. It consists of **four** types of **cells**, *viz*., **tracheids, vessels** (both **tracheary elements**), **xylem** or **wood parenchyma** and **xylem** or wood **fibres**. Out of these only tracheids and vessels take part in the transport of sap. They are hence called **tracheary elements**. Vessels are the main tracheary elements of angiosperms. They are absent in gymnosperms and pteriodophytes. In the last two groups, conduction of sap is carried out by **tracheids**. The conducting elements of the xylem have been called **hadrome** by Haberlandt (1914).

(a) **Tracheids**. The tracheids are elongated (5–6 mm **dead cells** with hard **lignified walls, wide lumen** and narrow end walls. In outline they are circular, polygonal or polyhedral.The inner walls of tracheids have various types of thickenings for mechanical strength. The unthickened areas allow the rapid movement of **water** from one tracheid to another. Tracheids constitute 90–95% of wood in gymnosperms while in angiosperms they hardly form 5% of the wood. Depending upon the thickenings, tracheids are of the following types (Fig. 6.12).

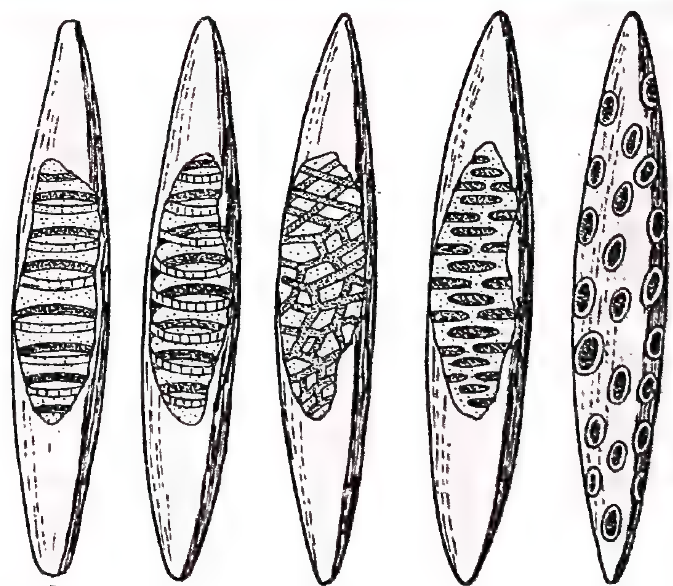


Fig. 6.12. Types of thickenings found in tracheids. A, annular; B, spiral; C, reticulate; D, scalariform; E, pitted.

(i) **Annular**. In this type the thickening material is laid down in the form of rings.

(ii) **Spiral** (Helical). The thickening is deposited like a **spiral** or helix. Both annular and spiral thickenings are present in the first formed tracheids because they allow considerable stretching.

(iii) **Reticulate**. Thickening is present in the form of a **network**. It is supposed

that it is formed by the presence of several spiral bands of thickenings which cross one another.

(iv) **Scalariform.** Here the thickenings give a **ladder** like appearance because they are laid down in the form of transverse bands.

(v) **Pitted.** It is the most advanced type of thickening. The pitted tracheids are uniformly thickened except for small unthickened areas called **pits**. In surface view they may appear circular, oval or angular. Pits often occur in pairs, that is, exactly at the same level on two adjacent elements. The pits are of two types, **simple** and **bordered**. The simple pits have **uniform width** of the **pit chamber** or **cavity**. In bordered pits the pit cavity is in the form of a **flask** with a narrow aperture and a wide base. The area of the primary wall and middle lamella, which is present in a pit, is called **pit membrane** or **closing membrane**. Actually it has many submicroscopic pores for the translocation of substances. A thickening called **torus** is present on the pit membrane of some gymnosperms for protecting the membrane from rupturing in case of unequal pressure on its two sides.

(b) **Vessels.** Vessels take part, like tracheids, in the **conduction of water** or **sap** and provide **mechanical** support. They are **much elongated** tubes (3-6 metres in *Eucalyptus*) which are closed at either end and are formed by the union of several short, wide and thickened cells called **vessel elements** or **members**. The end walls of vessel elements are transverse or oblique (Fig. 6.13 B-C). They are often completely dissolved (Fig. 6.13 A). The condition is called **simple perforation plate**. In a few cases the end walls remain intact and possess several pores in reticulate, scalariform or forminate forms. Such an end wall is called **multiple perforation plate** (Fig. 6.13 D), *e.g.*, *Liriodendron*, *Magnolia*. Vessels help in quick movement of water in the plant.

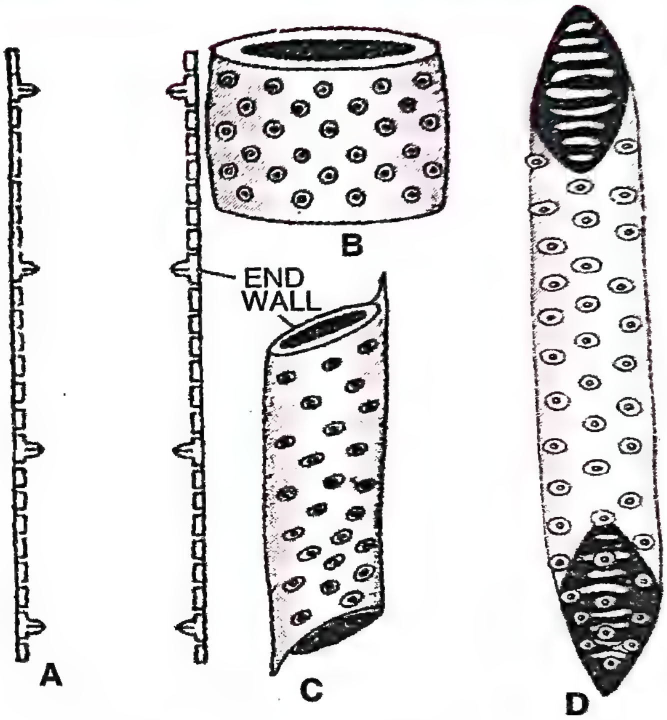


Fig. 6.13. Vessels. A, vessel in L.S. B–C, vessel elements with simple perforation plates. D, a vessel element with multiple perforation plate.

The walls of the xylem vessels are **lignified**. They are thickened variously— annular, spiral, reticulate, scalariform and pitted. The pitted condition is more common. In outline the vessels are **rounded** in monocots and **angular** in dicots. Vessels are absent in gymnosperms and pteridophytes with the exceptions of a few (*e.g.*, *Selaginella* species, *Gnetum*). Their tracheary elements comprise tracheids only. Flowering plants possess both vessels and tracheids but the latter are comparatively fewer.

Differences between Vessels and Tracheids

Vessels	*Tracheid*
1. A vessel is made of a number of cells.	1. A tracheid is formed from a single cell.
2. The ends are rounded or transverse.	2. The ends are generally oblique and tapering.
3. A vessel is several centimeters in length.	3. A tracheid is only a fraction of a centimeter in length.

4. The septa between adjacent cells get dissolved to produce a vessel.	4. The end walls or septa remain intact.
5. They are comparatively wider.	5. Tracheids are comparatively narrower.
6. The wall is less thickened.	6. The wall is more thickened.
7. The lumen is wide.	7. The lumen is comparatively narrower.
8. They occur in angiosperms and as occasional evolution in other vascular groups.	8. Tracheids occur in all vascular groups.

(c) **Xylem** or **Wood Parenchyma**. It is made of generally small thin or thick walled parenchymatous cells having simple pits. The wood parenchyma **stores food** (starch, fat) and sometimes tannins. It helps in the lateral conduction of water or sap. Ray parenchyma cells are specialised for this.

(d) **Xylem** or **Wood Fibres**. They are sclerenchyma fibres associated with xylem. Xylem fibres are mainly **mechanical** in function. They are **aseptate** but can be **septate**. Xylem fibres are of two types— (i) **Libriform Fibres**. Typical fibres with thick walls having simple pits and obliterated central lumens. (ii) **Fibre Tracheids**. Intermediate between fibres and tracheids having thin walls and pits with reduced borders.

Differences between Tracheid and Fibre

Tracheid	*Fibre*
1. It is a tracheary element.	1. It is a mechanical element.
2. Tracheid is found only inside xylem.	2. Fibre occurs inside xylem, phloem, around vascular bundle, inside pericycle, cortex, hypodermis, etc.
3. It is 1–6 mm in length.	3. A fibre can be 1mm to 90 cm in length.
4. Cell wall is comparatively less thickened.	4. Cell wall is comparatively more thickened.
5. The lumen is wide.	5. The lumen is narrow.
6. Thickening can be annular, spiral, reticulate, scalariform and pitted.	6. Fibre has pitted thickening.
7. Pits are generally bordered.	7. Pits are usually simple.

Differences between Xylem and Phloem (Fig. 6.14)

Xylem	*Phloem*
1. It conducts water or sap.	1. Phloem conducts organic food.
2. Xylem also provides mechanical strength.	2. Phloem has no mechanical function.
3. Xylem is usually found deep in the plant.	3. Phloem is usually situated towards the outer side of the plant.
4. In older plants, xylem often constitutes bulk of the plant body.	4. Phloem always forms a small part of the plant body.
5. The conducting or tracheary cells are dead.	5. The conducting cells are living.
6. Xylem is made up of three types of dead cells (vessels, tracheids, xylem fibres).	6. Phloem contains only one type of dead cells (phloem fibres).
7. There are one type of living cells (xylem parenchyma).	7. There are three types of living cells (sieve tube cells, companion cells and phloem parenchyma).
8. The conducting cells have lignin thickening in the wall.	8. Wall of the sieve tube does not possess lignin.
9. Conducting elements are of two types, vessels and tracheids.	9. Conducting elements are of one type, sieve tubes.
10. Tracheary elements have different types of wall thickenings.	10. Wall thickenings are absent in the conducting channels.
11. Vessels are devoid of septa.	11. Sieve tubes have bulging and porous septa.

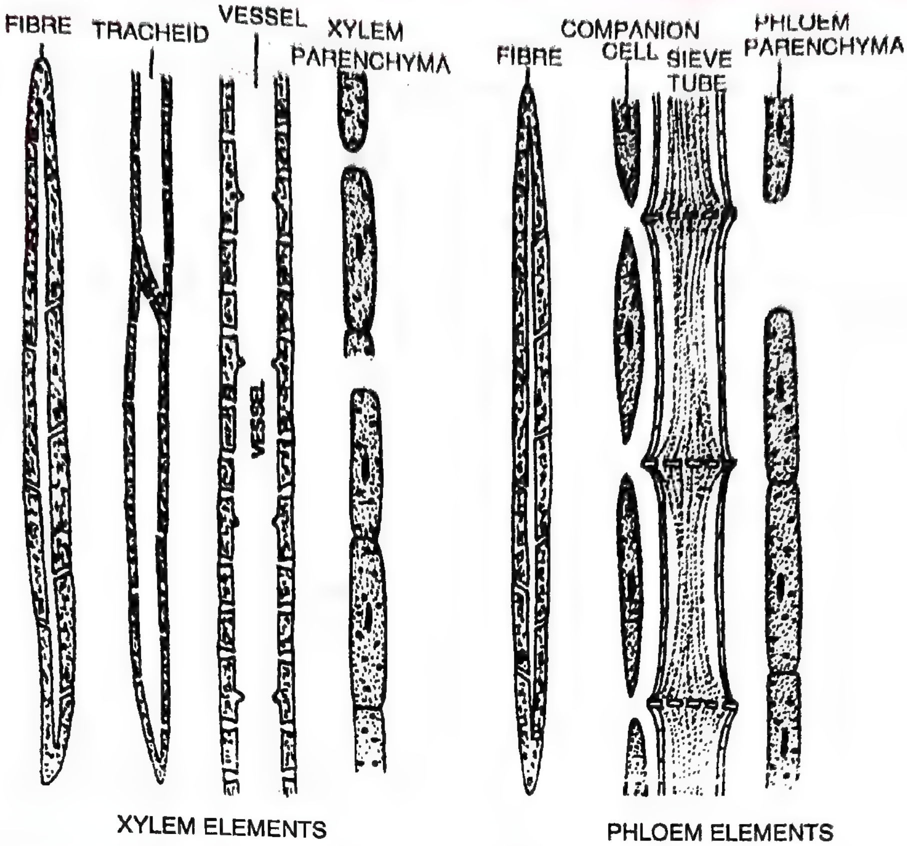


Fig. 6.14. Xylem and phloem elements.

Differences between Vessel and Sieve Tube

Vessel	*Sieve Tube*
1. It is a long distance channel for water transport.	1. Sieve tube is a long distance channel for transport of organic nutrients.
2. A vessel is made up of a large number of dead cells.	2. It is made up of number of living cells.
3. The wall is thick.	3. The wall is thin.
4. The wall possesses pits and other types of secondary thickenings.	4. Secondary thickenings are absent. Plasmodesmata occur instead.
5. The wall is lignified.	5. Lignification is absent.
6. The end walls between adjacent cells are completely dissolved.	6. The end walls are perforated with pores called sieve pits.
7. The region of end walls is not swollen or conspicuous.	7. The end walls are generally broader than the rest of the sieve tube elements.
8. In addition to transport, a vessel also helps in providing mechanical strength.	8. A sieve tube does not provide mechanical strength.

Differences between Vascular Tissues of Gymnosperms and Angiosperms

Vascular Tissues of Gymnosperms	*Vascular Tissues of Angiosperms*
1. Xylem is devoid of vessels.	1. Xylem possesses vessels.
2. Phloem does not contain sieve tubes.	2. Sieve tubes are present.
3. Phloem does not contain companion cells.	3. Phloem possesses companion cells.

Protoxylem and Metaxylem

Depending upon the time of **origin** in relation to the growth of the plant organ, the xylem is of two types, **protoxylem** and **metaxylem**. Protoxylem (Gk. *protos*— first, *xylem*—wood) is the **first formed xylem**, where lignification begins before the completion of elongation. It is made up of small **tracheids** and **vessels** which possess annular or spiral thickenings. They are capable of being stretched. The **later formed xylem** is described as **metaxylem** (Gk. *meta*— after, *xylem*—wood). It consists of **bigger tracheids** and **vessels** which have reticulate, scalariform or pitted thickenings. Lignification occurs in them after completion of elongation. Depending upon the **position** of protoxylem in relation to metaxylem, xylem can be of four types— **exarch, mesarch, centrarch** and **endarch.** In exarch (L. *ex*—without, Gk. *arche*—beginning) type, protoxylem lies towards the **outside** of metaxylem. Development of xylem is **centripetal**. It is **centrifugal** when protoxylem is **inner** in the endarch (Gk. *endon*—within, *arche*—beginning), **middle** of metaxylem in the **mesarch** xylem (Gk. *mesos*—middle, *arche*—beginning) and centre of metaxylem in centrarch xylem.

Differences between Protoxylem and Metaxylem

Protoxylem	*Metaxylem*
1. It is the first formed xylem.	1. It is the later formed xylem.
2. It develops before the plant organ has completed its growth.	2. It differentiates when the plant organ has completed its growth.
3. Protoxylem is comparatively less prominent.	3. Metaxylem is quite prominent.
4. It is made up of smaller and narrower elements.	4. Metaxylem is formed of broader and larger elements.
5. The wall thickenings of the conducting elements are of simple and primitive type– annular or spiral.	5. The wall thickenings are of complex and advanced type– reticulate, scalariform or pitted.
6. Lignification occurs in protoxylem elements before the completion of elongation of the plants.	6. Lignification occurs after the completion of elongation in the plant part.
7. Protoxylem elements are capable of being stretched.	7. Metaxylem elements cannot be stretched.
8. In many monocots, protoxylem elements get crushed during growth and the area comes to have a cavity.	8. Metaxylem does not get crushed.
9. Fibres are absent or rare.	9. Fibres often occur in metaxylem.

Differences between Exarch and Endarch Xylem

Exarch Xylem	*Endarch Xylem*
1. Protoxylem is towards the outer side of the organ.	1. Protoxylem is towards the centre of the organ.
2. Exarch condition of xylem is found in roots.	2. Endarch condition of xylem is found in stems.
3. Exarch xylem occurs in radial bundles.	3. Endarch xylem is component of collateral bundles.

Protophloem and Metaphloem

Protophloem is the first formed part of phloem which develops in parts that are undergoing enlargement. It consists of narrow enucleate sieve elements which may occur singly

or in groups amongst cells that often grow later into fibres. Companion cells may or may not be associated with protophloem. During elongation the protophloem elements (sieve elements) get stretched and become nonfunctional.

Metaphloem is part of primary phloem that differentiates in plant organs after they have stopped enlargement. The sieve elements are wider and longer. Companion cells are regularly associated. Fibres are absent but parenchyma cells may later become sclerified.

Differences between Protophloem and Metaphloem

Protophloem	*Metaphloem*
1. It is the first formed phloem when the plant organ is growing.	1. It is the later formed phloem which differentiates when the plant organ has completed its growth.
2. Protophloem is comparatively less prominent.	2. Metaphloem is quite prominent.
3. It is made up of smaller and narrower elements.	3. It is made up of longer and broader elements.
4. Sieve areas or pores are not prominent.	4. Sieve areas or sieve pores are quite prominent.
5. Companion cells are often absent.	5. Companion cells or their equivalents are usually present.
6. Protophloem is short lived and gets crushed.	6. It is long-lived but can be crushed during secondary growth.
7. In the region of crushed protophloem, fibres often develop from specialized cells.	7. Fibres may be present but specialized cells do not occur.

TISSUE SYSTEMS

Tissue system is a tissue or a group of tissues derived from a portion of meristem which performs a similar function in the plant body irrespective of its position. On the basis of their location and structure, Sachs (1875) recognises three tissue systems in plants— epidermal, ground and vascular.

Epidermal Tissue System

This tissue system forms the outermost covering of plant body. It is derived from protoderm. It consists of **epidermis** and **epidermal appendages.** Epidermis is made of epidermal cells and stomata.

1. **Epidermis** (Gk. *epi*— upon, *derma*— skin). Epidermis is the outermost protective layer of primary plant body. It is usually single layered. Multilayered epidermis occurs in the leaves of some tropical plants (*e.g.*, Oleander, Banyan) and aerial roots of orchids. Epidermis is a conspicuous layer of elongated, compactly arranged living cells which do not enclose intercellular spaces. The cells possess large central vacuoles and thin peripheral cytoplasm. They remain thin walled in roots and plants growing under moist conditions. The root epidermis is also called **piliferous layer** because it bears root hairs. Epidermal cells of the aerial parts of the plants have wavy lateral walls in dicots and straight walls in monocots. Their outer walls are cutinised. Cutin is a fatty-waxy substance. The cutinised walls are less permeable to water. The impermeability depends upon the thickness of cutin. Cutin also forms a separate layer on the outside of epidermis. It is called **cuticle**.

Under extremely dry conditions the cuticle is reinforced by a layer of **wax**. Wax produces

mealy coating or **bloom**. Wax is also present on the upper surface of floating leaves. It protects the floating leaves from wetting. In cereals the epidermal cells have a deposition of **silica**. Silica provides stiffness. It is also abrasive and hence protective against grazing.

The epidermis of aerial parts usually bears a number of minute pores called **stomata**. Stomata are absent in the surface layer of roots. They are fewer in case of stems but are abundant in case of leaves. Each stoma (singular of stomata) or stomate is surrounded by a pair of specialised epidermal cells called **guard cells**. Guard cells differ from rest of the cells in shape, size and thickenings. They also have a few small chloroplasts. The guard cells are generally bean or kidney shaped in most plants. They are dumb-bell shaped in grasses. Inner walls of the guard cells (towards the stamatal pore) are thick while the outer ones are thin. Stomata regulate transpiration and gaseous exchange with the help of their guard cells. The latter expand and contract in response to their turgidity and thus open or close the stomatal aperture.

In some cases the guard cells are surrounded or overtopped by another category of less modified epidermal cells called **subsidiary cells**. When subsidiary cells lie above the guard cells, the stomata are called **sunken**. Stomatal aperture, guard cells and subsidiary cells together constitute a complex called **stomatal apparatus**.

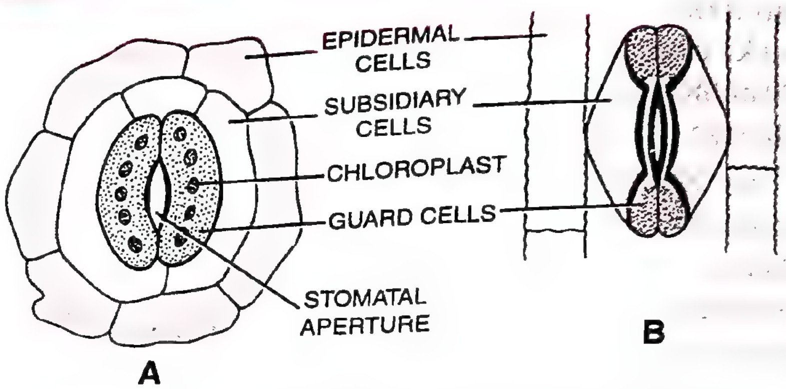


Fig. 6.15. Stomatal Apparatus. A, with bean shaped guard cells. B, with dumb-bell shaped guard cells.

In dorsiventral leaves the stomata occur mostly on the lower surface (hypostomatic) but in vertically oriented leaves and the plants growing in moist environment, they occur on both upper and lower sides (amphistomatic). In floating leaves of aquatic plants, they are restricted to the upper surface only (epistomatic).

2. **Epidermal Appendages**. They are of two types, trichomes and emergences.

Trichomes. They are unicellular or multicellular outgrowths which are strictly epidermal in origin. Trichomes are of two kinds, **hair** and **scales**. Hairs are elongated structures and can be unicellular or multicellular. Scales are multicellular flattened structures (*e.g., Nepenthes*)

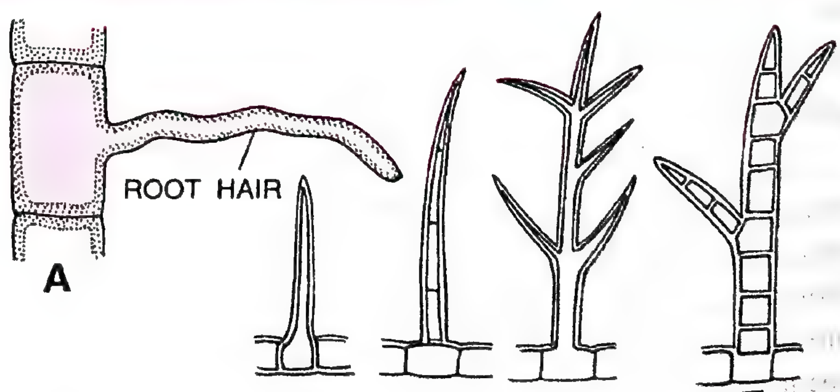


Fig. 6.16. Hair. A, root hair; B, unicellular unbranched hair of aerial surface. C, a multicellular hair of aerial surface. D, branched unicellular hair. E, branched multicellular hair.

(i) **Root Hairs** (Fig. 6.16A) They are unicellular tubular structures found in epiblema of root in a special area called root hair zone. Root hairs are actually not appendages or protubrances but are simply enlargements of epiblema cells called **trichoblasts**. Root hair cells have vacuolated protoplasm. Nucleus occurs towards the apical part of the hair. Wall is thin and pectocellulosic. Root hairs are ephemeral. New root hairs are

continuously developed on young parts of the root. Root hairs take part in absorption of water and mineral salts. They also hold the soil particles and play an important role in anchoring the plant.

(ii) **Aerial Hairs** (Fig. 6.16 B–E). They are unicellular or multicellular appendages which are covered by a layer of cuticle. Unicellular hairs are simple and often unbranched. Multicellular hair are more abundant. They can be unbranched or branched. The hair enclose stationary air and protect the plant organs against sudden changes of temperature and high rate of transpiration. Cotton is obtained from long unicellular epidermal hair or **lint** (*c.f.*, fuzz) of *Gossypium* seeds. A single seed may have upto 1000 lint hair (Fig. 6.17). One kg of cotton contains over 200 million hair. The hair have cellulose thickening.

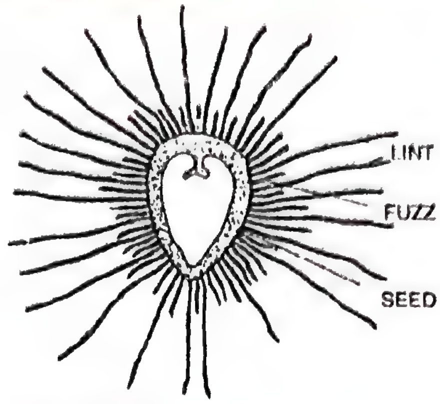


Fig. 6.17. Cotton seed with lint and fuzz hair.

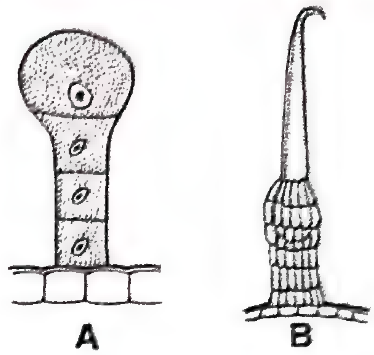


Fig. 6.18. A, gland hair of Citrus. B, stinging hair of Nettle.

(iii) **Stinging Hairs**. They are hollow hairs that contain siliceous tips and enclose a highly irritant and inflammatory liquid having a cocktail of histamine, serotinin, formic acid, tartaric acid and oxalic acid. It is injected into the skin of animals rubbing against them, *e.g., Urtica dioica* (Fig. 6.18 B, Stinging Nettle).

(iv) **Glandular Hairs**. Most of the glandular trichomes produce essential oils (Fig. 6.18 A). They provide characteristic odour to plants, *e.g., Citrus*, Mint. The digestive glands of insectivorous plants are also trichome in nature.

Emergences. They are multicellular epidermal outgrowths which also contain some inner tissues. **Prickles** are an example of emergences. They are sharp and stiff outgrowths. Prickles do not have vascular supply. They protect the plant from excessive transpiration, grazing animals and in some roses help the plants in climbing.

Functions – (i) Being the outermost layer, it is protective in nature. (ii) It forms water and mineral absorptive system of the root. (iii) With the help of cuticle it checks the rate of water loss from aerial parts. (iv) Presence of epidermal hair form an insulating layer over the surface. (v) Prickles and stinging hair protect the plant from herbivores. (vi) Glandular hairs provide aroma to the plants. (vii) Stomata take part in exchange of gases and transpiration. (viii) Trichomes present on the surface of some seeds and fruits help in their dispersal.

Ground Tissue System

The system is formed from ground meristem or partly plerome and partly periblem that forms the interior of plant organs with the exclusion of epidermal and vascular systems. It consists of simple permanent tissues like parenchyma, collenchyma and sclerenchyma. Ground tissue system of leaves is called **mesophyll**. Mesophyll is made up of two types of photosynthetic cells, **palisade** and **spongy**. Palisade parenchyma occurs towards the upper surface. It is formed of columnar cells. Abundant chloroplasts occur in these cells. Intercellular spaces are quite narrow. Spongy parenchyma occurs towards the lower epidermis and encloses large intercellular spaces. Its cells are rounded, isodiametric, angular or lobed. They contain good number of chloropolasts.

The ground system of monocot stem has two parts, hypodermis and ground paren-

chyma. In roots and dicot stems, the ground tissue system is differentiated into hypodermis, cortex, endodermis, pith and medullary rays. Pericycle is actually constituent of vascular tissue system but is often included in ground tissue system.

1. **Hypodermis.** It forms a few layers of collenchyma or sclerenchyma that lies below the epidermis. It provides mechanical strength and rigidity. In aerial stems it additionally functions as heat screen.

2. **Cortex.** Cortex is commonly thin-walled parenchymatous region that lies between endodermis and hypodermis/epidermis. It stores food and performs some additional functions like enclosing large air cavities in aerenchyma and performing photosynthesis if chlorenchymatous. In stem the primary function of cortex is the formation of protective zone. Its secondary function is storage of food. Accessary functions include photosynthesis and retention of gases if aerenchymatous. In roots, the primary function of cortex is storage of food. In root hair zone it is transfer of absorbed water and minerals to the interior.

3. **Endodermis.** Endodermis is the innermost layer of cortex that consists of tightly packed barrel shaped cells. It is called **starch sheath** in case of dicot stems. In roots its cells possess ligno-suberin **casparian strips** or **bands**. Major function of endodermis is to act as check post between vascular strand and cortex.

4. **Pericycle.** It is the outer boundary of vascular strand that is one to several cells in thickness. In roots it gives rise to lateral branches. Part of vascular cambium is also formed by it. Pericycle of yound roots is made up of thin walled cells. In stem pericycle may be parenchymatous, sclerenchymatous or both. Sclerenchymatous pericycle is both protective and supportive. Parenchymatous pericycle helps in exchange of material between cortex and vascular bundles. Pericycle is absent in stems and roots of aquatic plants.

5. **Pith.** It lies in the centre and is often parenchymatous. It is well developed in dicot stems and monocot roots. Intercellular spaces may or may not be present. Pith is repository of many excretory substances like tannins, phenols, calcium, etc. It may also store food.

6. **Medullary Rays.** They are nonvascular areas which occur between vascular bundles in dicot stems for lateral conduction.

Vascular Tissue System

It forms a strand of vascular tissues that is known as **vascular strand** or vascular cylinder. In gymnosperms and flowering plants, the vascular tissues occur in distinct patches called **vascular bundles**. The latter are **radial** in roots and **conjoint** in case of stems and leaves (Fig. 6.19).

1. **Radial Bundles.** Here xylem and phloem occur in the form of separate bundles called **xylem bundles** and **phloem bundles**. The two types of bundles usually alternate with each other. They occur on different radii. Radial bundles are characteristic of roots.

2. **Conjoint Bundles.** The vascular bundles which contain both xylem and phloem are called conjoint vascular bundles. Conjoint bundles are of the following three types.

(i) **Collateral Bundles.** They are those conjoint bundles in which phloem and xylem lie together on the same radius with phloem on the outer side and xylem towards the inner side. In gymnosperms and dicot stems a strip of vascular cambium occurs between phloem and xylem of each vascular bundle. It is called **intrafascicular** (or fascicular) **cambium.** This strip of vascular cambium later produces secondary tissues. Such vascular bundles are described as **open** because the original or primary phloem and xylem separate on the production of secondary tissues by vascular cambium. In monocot stems vascular bundles do not have a strip of vascular cambium. They are termed as **closed**.

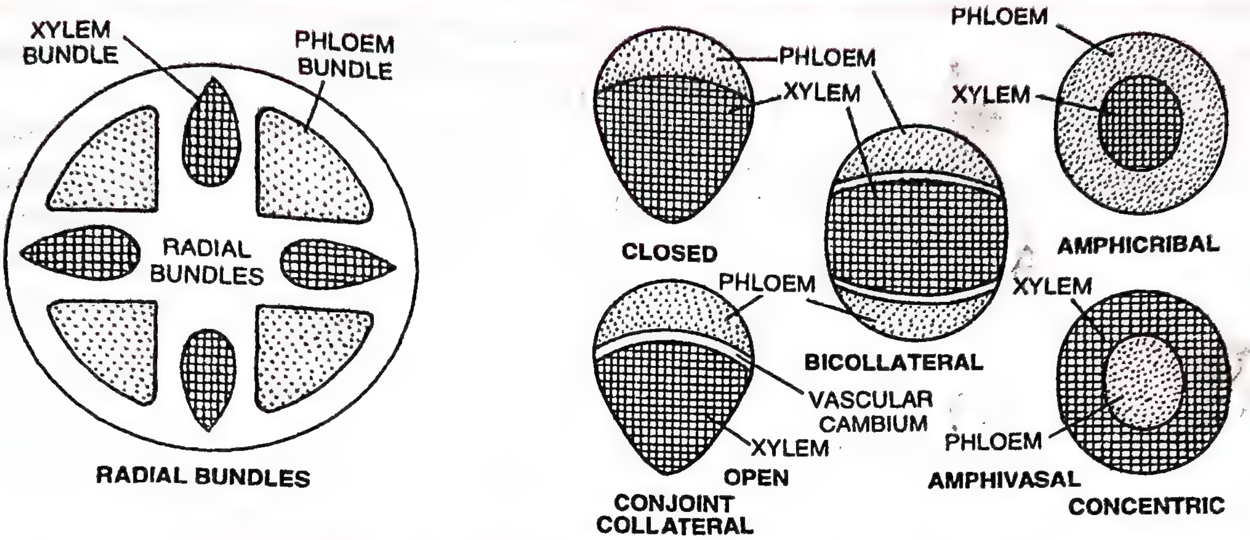


Fig. 6.19. Types of vascular bundles.

Differences between Open and Closed Vascular Bundles

Open Vascular Bundle	*Closed Vascular Bundle*
1. Vascular bundle contains a strip of cambium in between phloem and xylem.	1. Intrafascicular cambium is absent.
2. Phloem and xylem do not lie in direct contact with each other.	2. Phloem and xylem occur in direct contact with each other.
3. Due to activity of cambium, original or primary phloem and xylem move away from each other. Secondary phloem and secondary xylem are formed in between.	3. There is no such activity.
4. Open vascular bundles occur in dicot and gymnosperm stems.	4. Closed vascular bundles are found in leaves and monocot stems.
5. Open vascular bundles can be collateral and bicollateral.	5. Closed vascular bundles can be collateral or concentric.

(ii) **Bicollateral Bundles**. Bicollateral vascular bundles have phloem both on the outer and inner side of xylem. All the three lie on the same radius. Usually a strip of vascular cambium is present on both outer and inner sides of xylem. Bicollateral bundles occur in Cucurbitaceae (*e.g.*, Pumpkin or *Cucurbita pepo*, Ridge gourd or *Luffa cylindrica*) and some members of families Solanaceae, Convolvulaceae, etc.

Differences between Collateral and Bicollateral Vascular Bundles

Collateral Bundle	*Bicollateral Bundle*
1. It contains a single patch of phloem.	1. There are two patches of phloem.
2. Phloem lies towards the outer side and xylem towards the inner side.	2. Phloem occurs both on the outer side as well as on the inner side. Xylem occupies the central position.
3. If open, a collateral bundle contains a single strip of cambium.	3. A bicollateral bundle is often open. It contains two strips of cambium, outer and inner.

(iii) **Concentric Bundles.** Here out of the two types of vascular tissues (phloem and xylem), one forms a solid core while the other surrounds it completely on all sides. A strip of vascular cambium is always absent. Concentric bundles are of two kinds:

(a) **Amphicribal (Hadrocentric) Bundle.** Xylem forms a central core while phloem surrounds it on all sides. It occurs in some aquatic angiosperms and the staminal bundles of many dicots (*e.g.*, *Prunus*).

(b) **Amphivasal (Leptocentric) Bundle.** Phloem lies in the centre of the vascular bundle which is completely surrounded by xylem, *e.g.*, *Dracaena, Yucca.*

ANATOMY OF DICOTYLEDONOUS AND MONOCOTYLEDONOUS PLANTS

PRIMARY DICOT ROOT (Figs. 6.20-21)

A young dicot root which possesses only primary permanent tissues derived from the apical growing point is called **primary dicot root.** It is cylindrical in outline and possesses the following tissues (Fig. 6.21).

1. **Epiblema or Piliferous Layer** (Rhizodermis). It is the outermost layer of the root. It is made of compactly arranged thin-walled flattened and slightly elongated parenchymatous cells. Epiblema of root differs from the epidermis of stem in being devoid of distinct cuticle and stomata. Some cells of the epiblema give rise to thin-walled tubular outgrowths called **root hairs**. They are called **trichoblasts**. Trichoblasts are generally smaller than other epiblema cells. The root hairs lie in between the soil particles and are in contact with the soil water. Root hairs possess a gummy pectic layer on the outside for cementing with soil particles and retaining water on the surface. Due to the presence of root hairs, the epiblema is also called **piliferous layer** (L. *pilus*— hair, *ferre*— to carry). The root hairs and thin-walled epiblema cells **absorb water** and **minerals salts** from the soil. Root hairs commonly do not live for more than one week. With their death the epiblema cells become suberised and cutinised.

Differences between Stem and Root Hairs

Stem Hairs	*Root Hairs*
1. They are generally multicellular.	1. Root hairs are unicellular.
2. Stem hairs are additional cells. They do not arise as outgrowths of the epidermal cells.	2. Root hairs are tubular outgrowths of epiblema cells.
3. They may be branched or unbranched.	3. Root hair are always unbranched.
4. They are spread all over the stem.	4. They are found in clusters in young roots near their tips. It is known as root hair zone.
5. Stem hairs are heavily cutinised.	5. Root hairs are not cutinised.
6. They are long-lived.	6. They are short lived.
7. Stem hairs prevent or reduce the rate of transpiration.	7. Root hairs take part in absorption of water from the soil.

2. **Cortex.** It lies below the epiblema. The cortex is made up of many layers of thin walled parenchyma cells. The parenchyma cells may be rounded (*e.g.*, *Cicer*) or angular (*e.g.*, Sunflower). They enclose intercellular spaces for diffusion of gases. The cells of the cortex **store food.** They also **conduct water from the epiblema to the inner tissues.**

3. **Endodermis.** Endodermis is usually considered to be the innermost layer of the

cortex. It is made up of a **single** layer of barrel-shaped cells which do not enclose intercellular spaces. The cells are rich in starch grains. The young endodermal cells possess a band of thickening which runs along their radial and tangential walls. This band of thickening is called **casparian strip** (after Caspary, 1865; Fig. 6.20). It is made up of both suberin and lignin (Esau, 1965). In a transverse section, the casparian strip appears in the form of small lenticular swellings on the radial walls only. Casparian strips prevent plasmolysis of endodermal cells. Due to the presence of casparian strips, the endodermal cells do not allow wall to wall movement of substances between cortex and pericycle. Substances must enter the cytoplasm of endodermal cells. As a result, endodermis functions as a **biological check post.** All tissues on the inner side of endodermis constitute **stele.** It consists of pericycle, vascular bundles and pith.

4. **Pericycle.** Endodermis is followed by one (*e.g.*, Sunflower) or more (*e.g.*, Mulberry) layers of pericycle. Pericycle is believed to represent the outer boundary of vascular strand. The cells of pericycle are thin-walled and parenchymatous in the young root. Pericycle is a very important layer. A part of the vascular cambium is formed by the pericycle. The cork cambium also develops from it. All lateral roots originate from the pericycle. Pericycle is absent in the roots of some aquatic plants and parasites.

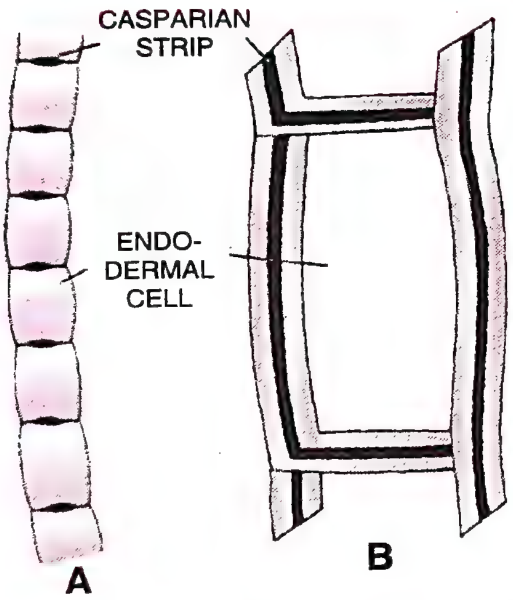


Fig. 6.20. Endodermal cells with casparian strip. A, T.S.; B, position of casparian strip in a cell.

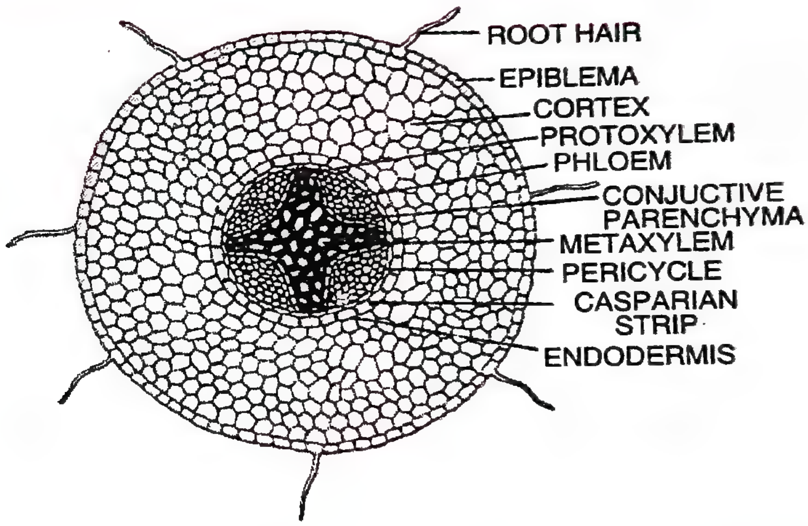


Fig. 6.21. T.S. Dicot root of Sunflower.

5. **Vascular Strand** or **Cylinder**. Inner to the pericycle are found a few (2–6) alternately arranged **bundles** of **xylem** and **phloem**. They are equal in number and lie on different radii. Such vascular bundles are called **radial bundles**.

The various **xylem bundles** put together give a stellate or star-shaped appearance. The number of rays is equivalent to the number of xylem bundles (and phloem bundles). According to the number of rays, the root may be **diarch** (with 2 xylem bundles, *e.g.*, Tomato), **triarch** (Pea), **tetrarch** (Buttercup, Gram, Sunflower, Castor), **pentarch** (with 5 xylem bundles) or **hexarch** (with 6 xylem bundles). In some cases different divisions of roots possess different number of strands, *e.g.*, two in lateral roots and four in main roots of Garden Nasturtium. Such roots are called **heteroarch**.

Protoxylem or the first formed xylem lies in contact with pericycle and at the tip of the rays while **metaxylem** or later formed xylem is present towards the centre of the root. Such a xylem is called **exarch** (L. *ex*— outside, Gk. *arche*— beginning). The metaxylem elements of different xylem bundles may lie separate from one another so that a **pith** is present in the centre of the root (*e.g.*, Gram, Bean). However, usually the xylem bundles extend along the radii so that metaxylem elements of different bundles meet in the centre to form a solid star-shaped structure. In such a case the pith is absent.

Xylem is made up of vessels and a few tracheids. Vessels and tracheids are polygonal in outline. Protoxylem elements are fewer, **smaller** and **narrower**. The metaxylem elements are **larger** and **wider**. They have pitted thickenings while protoxylem possesses spiral, annular, reticulate or scalariform thickenings. Xylem performs two important functions: (i) mechanical strength, (ii) conduction of water and mineral salts to the shoot.

In between the two adjacent xylem bundles is found a **phloem bundle**. It is oval in outline. Phloem and xylem bundles are separated from each other by one or more layers of small thin walled cells called **conjunctive parenchyma** or **tissue**. Later on the conjunctive tissue becomes meristematic to form **vascular cambium**.

Phloem consists of sieve tubes, companion cells and phloem parenchyma. It conducts organic food from the shoot to the root and its branches. Fibres may occur outside the phloem in some roots (*e.g.*, Gram).

Radial arrangement of vascular bundles is a mechanism to keep the xylem bundles in direct contact with the outer tissues of the root which conduct water absorbed by the root hairs to the inside.

6. **Pith**. It is often absent. When present, the pith is quite small. The latter is made of parenchyma cells. Intercellular spaces are absent. The cells store food as well as waste materials.

MONOCOT ROOT (Figs. 6.22-23)

There is no such distinction between a young and an old root of a monocotyledonous plant. This is due to the **absence of secondary growth** in the monocot roots. Typical monocot root consists of the following parts (Fig. 6.22).

1. **Epiblema** or **Piliferous Layer** (Rhizodermis). It is the outermost layer of young root which has thin-walled cells. Some of the cells give rise to root hairs. They have a gummy pectic layer on the outside for cementing with soil particles and retaining water. Root hairs are tubular in outline and lie in contact with soil water. Both epiblema and root hairs are

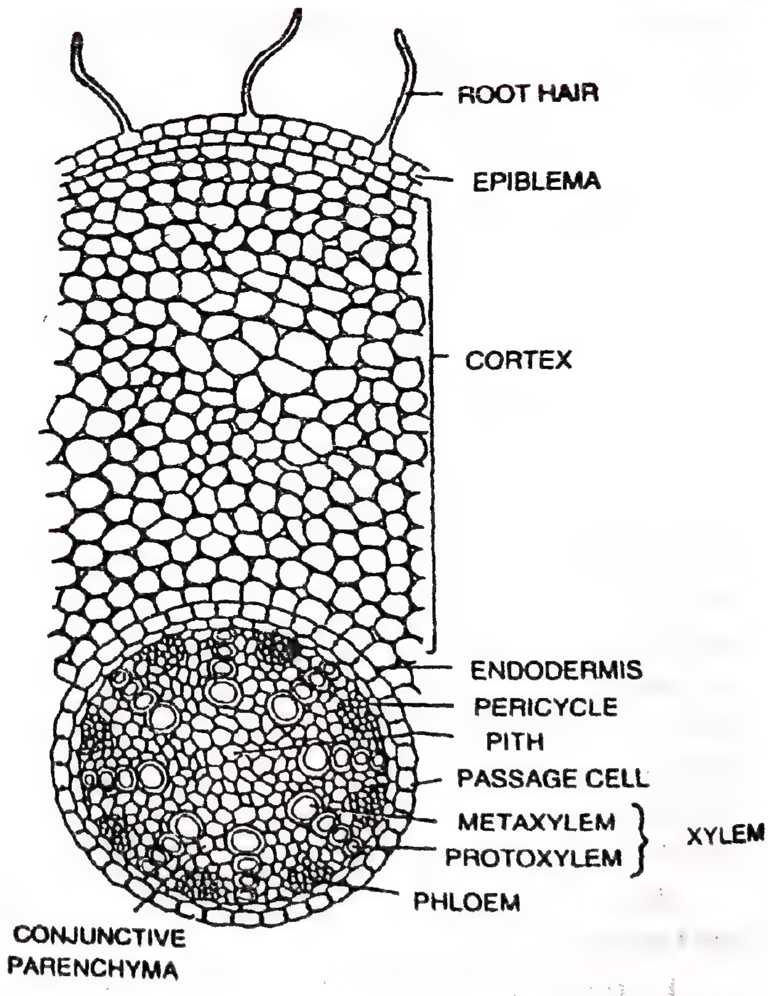


Fig. 6.22. T.S. Part of typical monocot root.

devoid of cuticle. They take part in the absorption of water and mineral salts. In older parts the epiblema is shed or becomes impervious.

2. **Cortex.** It is very wide region of parenchyma cells that enclose intercellular spaces for the exchange of gases. The cells store food. In older roots the outer one (*e.g.*, *Smilax*) or more (*e.g.*, Maize) layers of the cortex become thick walled and suberised. They constitute the **exodermis**. It is protective and to some extent absorptive in function.

The cortex of a monocot root has, therefore, three functions: (i) conduction of water from the root hairs to the inner tissues (ii) storage of food (iii) the outermost layer or layers of the cortex produce protective exodermis in the older roots.

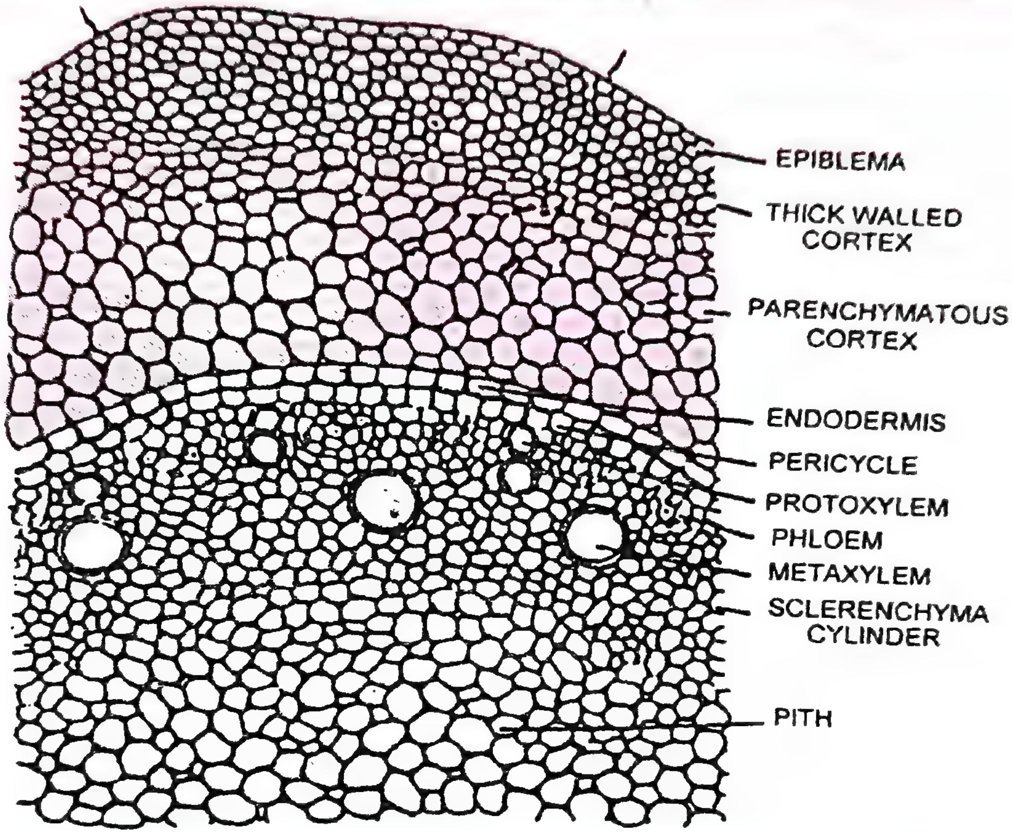


Fig. 6.23. A part of T.S. of monocot root of Maize (*Zea mays*).

3. **Endodermis.** Endodermis or inner boundary of the cortex is single layered. It is made up of barrel-shaped cells which do not enclose intercellular spaces. The young endodermal cells possess an internal strip of suberin and lignin which is known as **casparian strip**. However, it soon becomes indistinguishable due to the additional thickening of the endodermal cells. Endodermal cells lying opposite the protoxylem groups, however, remain in the primary stage with usual casparian strip (Zeiglar *et al*, 1963). These unthickened cells are called **passage or transfusion cells**. The passage cells are meant for the conduction of fluids inwardly from the cortex and outwardly from the interior into the cortex. The thickened cells can also allow transport through plasmodesmata of pits (Clarkson and others, 1968).

The endodermis **regulates the flow of fluid** both inwardly as well as outwardly by functioning as biological check post.

4. **Pericycle.** Pericycle or outer boundary of vascular strand lies below the endodermis. Pericycle may be uniseriate (single layered, *e.g.*, Maize) or multiseriate (multilayered, *e.g.*, *Smilax*). In monocots the pericycle does not form cambium. It only produces lateral roots.

The pericycle is composed of thin-walled parenchymatous cells in the young root. But later on it becomes thick-walled in many monocots.

5. **Vascular Strand** or **Cylinder.** It is in the form of several (8 or more) **alternate** and **radial xylem** and **phloem bundles**. The number is 20–30 in Maize and 100 or more of each type in *Pandanus* and palms. In many cases the vascular bundles are embedded in a cylinder of sclerenchymatous conjunctive tissue (*e.g.*, Maize). The vascular bundles are arranged in the form of ring around a central pith. The **xylem bundles are exarch**, *i.e.*, protoxylem lies towards the outside while the **metaxylem** faces inwards. Because of the presence of numerous xylem bundles and exarch condition, xylem of monocot root is **polyarch.** Xylem is made up of **rounded** or **oval** vessels and xylem parenchyma. The vessels of metaxylem are larger than those of protoxylem. Protoxylem vessels are narrow. They have a spiral annular or reticular thickenings. Metaxylem vessels are broad. Usually they possess pitted thickenings. Xylem provides mechanical strength and helps in the conduction of water and mineral salts.

Phloem bundles alternate with the xylem bundles. These two are separated from each other by means of narrow strip of **conjunctive tissue**. The cells of this tissue store food if parenchymatous. They provide mechanical strength on becoming sclerified. They do not take part in the formation of cambium.

Phloem consists of sieve tubes and companion cells. It helps in the **conduction of organic** food. A distinction between protophloem and metaphloem may or may not be present.

6. **Pith**. The centre of monocot root is occupied by the pith. It consists of parenchymatous (thin-walled or thick-walled) cells which may be rounded or angular. Intercellular spaces are present amongst the pith cells. The pith cells store **food.**

Differences between Dicot and Monocot Root

Dicot Root	*Monocot Root*
1. Cortex is comparatively narrow.	1. Cortex is very wide.
2. The epiblema, the cortex and even the endodermis are peeled off and replaced by cork.	2. Cork is not formed. The cortex and the endodermis persist. Only the epiblema is peeled off.
3. Older root has a covering of cork.	3. Older root has a covering of exodermis.
4. Endodermis is less thickened and casparian strips are more prominent.	4. Casparian strips are visible only in young root. The endodermal cells later become highly thickened.
5. Passage cells are generally absent in endodermis.	5. Thin walled passage cells generally occur in the endodermis opposite the protoxylem point.
6. Pericycle produces lateral roots, cork cambium and part of the vascular cambium.	6. Pericycle produces lateral roots only.
7. The number of xylem and phloem bundles varies from 2-5 or sometimes 8.	7. Xylem and phloem bundles are numerous and are 8 or more in number.
8. Xylem vessels are generally angular.	8. Xylem vessels are oval or rounded.
9. Conjunctive tissue is parenchymatous.	9. Conjunctive tissue may be parenchymatous or sclerenchymatous.
10. Conjunctive parenchyma forms the cambium.	10. Conjunctive parenchyma does not produce cambium.
11. Secondary growth takes place with the help of vascular cambium and cork cambium.	11. Secondary growth is absent.
12. Pith is either absent or very small.	12. A well-developed pith is present in the center of the root.

SECONDARY GROWTH IN DICOT ROOT (Figs. 6.24-25)

Secondary growth is the growth in thickness due to the formation of secondary tissues by lateral meristems. With the exception of some annuals, most of the dicots and gymnosperms show secondary growth in their roots. It takes place by the production of two types of secondary tissues. They are **secondary vascular tissues** and **periderm**. These tissues are formed by meristems, **vascular cambium** and **cork cambium** respectively.

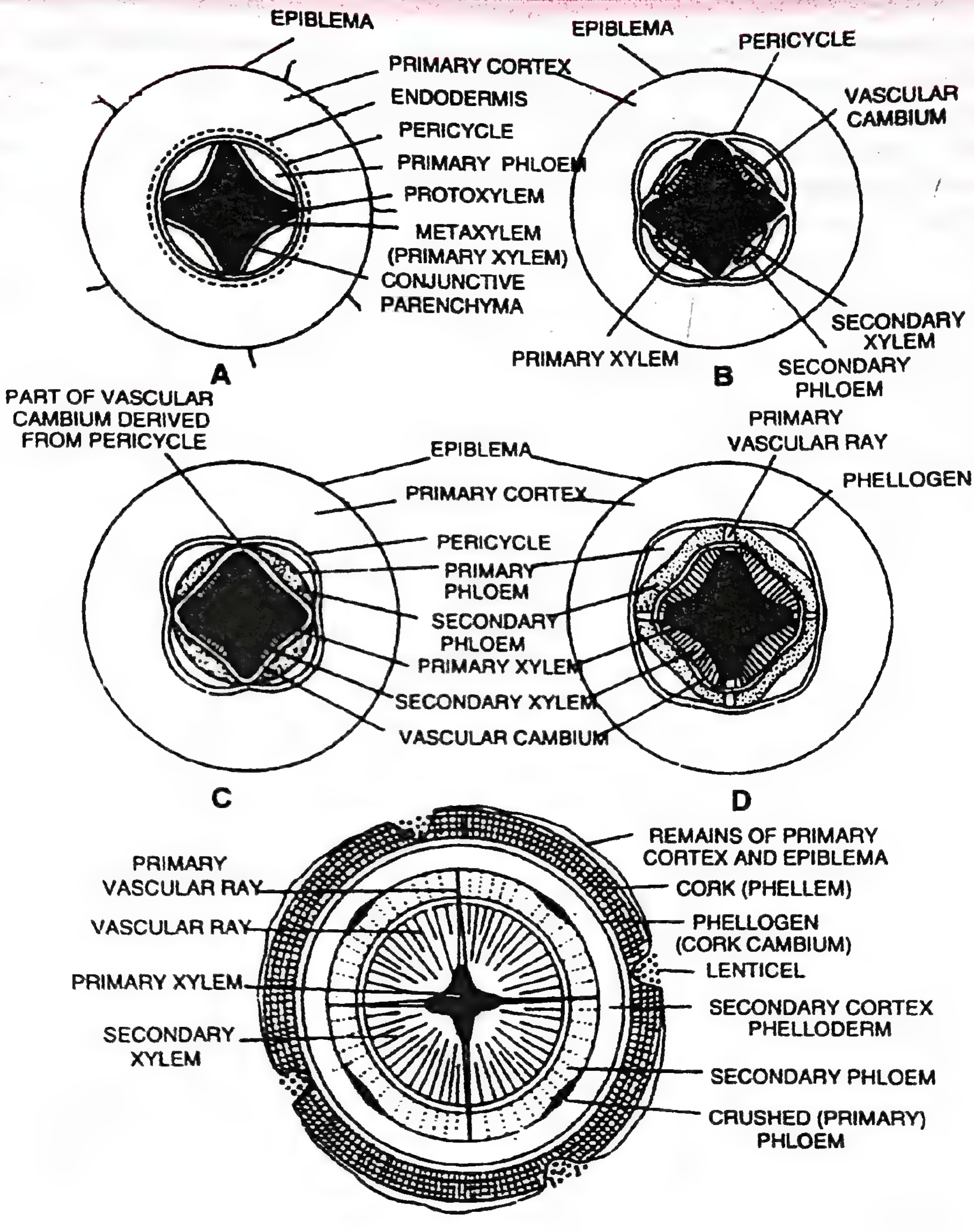


Fig. 6.24. Stages in secondary growth of a Dicot Root.
A, root with vascular strand; B, initial formation of secondary xylem and some secondary phloem and pushing out of the primary phloem; C, ring of vascular cambium completed; D, straightening of the cambial ring and formation of primary vascular rays; E, narrowing of primary vascular rays and formation of phellogen or cork cambium; completed secondary growth (diagrammatic).

1. **Secondary Vascular Tissues. Stage I** (Fig. 6.24 B). Conjunctive parenchyma cells lying on the inner edges of the primary phloem bundles become meristematic. They give rise to small quantity of secondary xylem on the inner side and secondary phloem on the outer side. In the process, these cambial strips and primary phloem bundles are pushed slightly to the outside. **Stage II**. Conjunctive parenchyma cells on the lateral sides of the phloem bundles as well as pericycle cells lying outside the protoxylem ends become brick-shaped and meristematic. This gives rise to a wavy band of a vascular cambium (Fig. 6.24 C). The vascular cambium of the root is a **complete secondary meristem**. It continues to form secondary xylem on the inner side and secondary phloem on the outer side. Secondary phloem consists of sieve tubes, companion cells, phloem parenchyma and phloem fibres. Secondary xylem is similarly made of vessels, xylem parenchyma and xylem fibres. **Stage III**. Initially vascular cambium derived from the pericycle gives rise to only ray cells. Hence wide multiseriate **primary vascular rays** (also called **medullary rays**) are formed opposite the protoxylem points. However, the formation of ray cells is slower than the formation of secondary vascular tissues. As a result the depressed parts of vascular cambium move outwardly and ultimately the cambium becomes circular (Fig. 6.24 D). **Stage IV**. The **ring** of **vascular cambium** produces **secondary xylem** on the **inner** side and **secondary phloem** to the **outside**. Both of them are in the form of rings (Fig. 6.24 D-E) (*c.f.*, primary vascular bundles). The primary phloem gets crushed by the growth of secondary vascular tissues. The older secondary phloem is also partially destroyed as the new phloem becomes functional. The primary and secondary xylems persist. Primary xylem is distinguishable by its exarch nature and central position. As compared to the primary xylem, the vessels of the secondary xylem are broader and thinner. Annual rings are not very sharp because unlike aerial climate, the climate of the soil does not vary much during different seasons.

The **secondary phloem** is made up of sieve tubes, companion cells and phloem parenchyma. Sclerenchyma fibres are rare. The **secondary xylem** is formed of vessels, tracheids and xylem parenchyma.

At places the vascular cambium possesses **ray initials**. They produce **vascular rays**. The rays are made up of two parts, **xylem** or **wood ray** (present in secondary xylem) and **phloem ray** (present in secondary phloem). They help in radial conduction of substances.

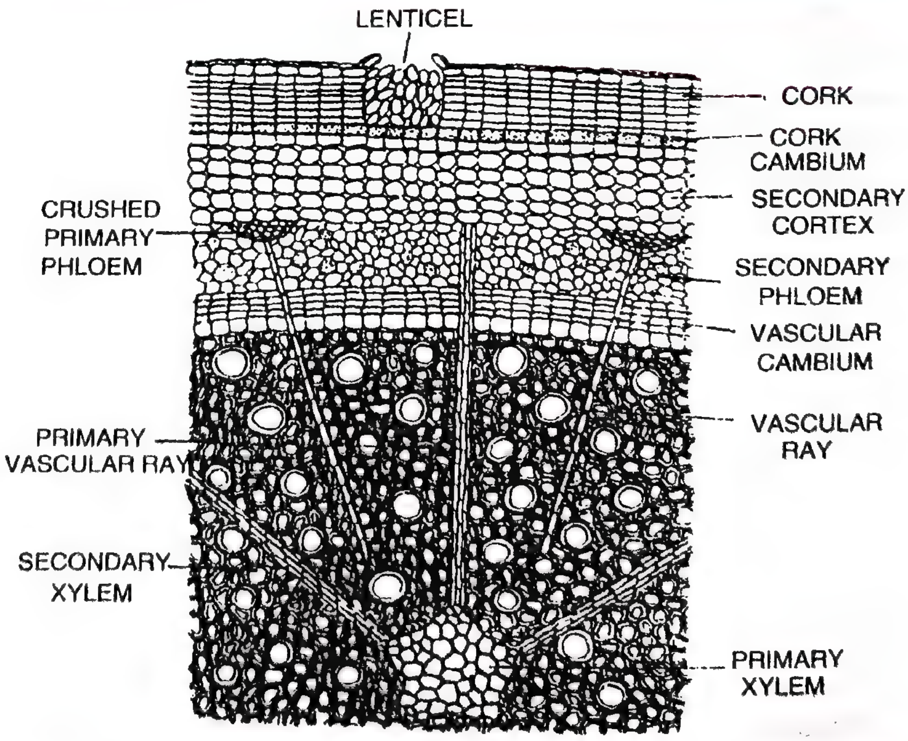


Fig. 6.25. A part of T.S. of an old dicot root showing secondary growth and a lenticel.

2. **Secondary Ground Tissues or Periderm (Stage V)**. The pericycle layer, either directly or after a few divisions becomes converted into a secondary meristem called **cork cambium** or **phellogen** (Fig. 6.24 D-E). Rarely phellogen appears in the cortex. The cells of phellogen divide both towards

the outside as well as inside. The tissue formed towards the **inner side** is parenchymatous and known as **secondary cortex** or **phelloderm.** It is only a few layers in thickness.

The cells formed on the **outside** by the phellogen are rectangular and compactly arranged. They soon become dead. Their cavities get filled up with tannin and their walls become suberised. They are described as cork cells. The tissue of cork cells is spoken as **cork or phellem** (Fig. 6.24 F). The cork is impervious to water. It protects the interior from mechanical injury and entry of bacteria. Primary tissues present outside the cork undergo starvation and get shrivelled. Under the impact of secondary growth in the interior, the outer layers of the cork are also peeled off occasionally. The phellem, the phellogen and the phelloderm are collectively called secondary ground tissue or **periderm.** At places the phellem or cork bears **lenticels** for exchange of gases (Figs. 6.24 E, 6.25).

PRIMARY DICOT STEM (Fig. 6.26)

In outline, primary dicot stem may be circular (*e.g.*, Sunflower) or angular (*e.g., Cucurbita*). The various tissues of the primary dicot stem are arranged in concentric fashion. From outside to inside they are as follows :

1. **Epidermis.** Epidermis is the **outermost** layer of the stem. It is made up of compactly arranged elongated parenchymatous cells, which look rectangular-barrel shaped in a transverse section. The cells are transparent and devoid of chloroplasts. The outer walls are convex, thickened and cutinised. On the outer side they possess a layer of **cuticle.** The internal walls of the epidermal cells are thin. The radial walls are thick towards the outer side and gradually become thin towards the inner side. Pits occur in the radial walls.

The epidermis of Sunflower stem bears several unbranched multicellular **hair** or trichomes. Like epidermis, they are covered by cuticle. At places the epidermis contains minute pores called **stomata** or **stomates.** Each stomate or stoma (sing. of stomata) has a pair of specialised **kidney shaped cells** called **guard cells.** The guard cells have a few **chloroplasts.** By their swelling, the two guard cells can form a pore in between them.

The various **functions** of the epidermis are (i) protection of internal tissues, (ii) prevention of entry of harmful organisms, (iii) minimising surface transpiration by having thick cuticle, (iv) exchange of gases through the stomata, (v) protection against excessive heating up and sudden changes in temperature with the help of hair (as in Sunflower).

The tissue between epidermis and pericycle is called **Cortex.** It has three parts—hypodermis, general cortex and endodermis.

2. **Hypodermis.** The hypodermis is made of 3–4 layered sub-epidermal **collenchyma** tissue. Its cells possess extra cellulose thickening in various regions— on the tangential walls (lamellate collenchyma, *e.g.*, Sunflower), at the angles (angular collenchyma, *e.g.*, Castor) and near the intercellular spaces (lacunate collenchyma, *e.g., Cucurbita*). Collenchyma cells are green and enclose small intercellular spaces. Hypodermis functions in (i) providing mechanical strength as well as flexibility, (ii) storage of food and (iii) manufacture of food with the help of chloroplasts. Hypodermis is absent or inconspicuous below the stomata.

3. **General Cortex.** It is a few to several cells in thickness. The cortex is made up of **thin walled** angular (*e.g.*, Castor), oval or rounded (*e.g.*, Sunflower) parenchymatous cells. They enclose intercellular **spaces.** In the young green stem, the outer cortical cells possess chloroplasts (chlorenchyma) and manufacture food. However, major **function** of the cortex is **storage** of food. In Sunflower the cortex contains a number of longitudinally running **oil ducts.** Each oil duct has a channel which is lined by an epithelium of small glandular cells.

4. **Endodermis.** It is a **wavy layer** of one cell in thickness. The endodermis lies at the **innermost** boundary of cortex. It is made up of barrel-shaped cells which do not enclose intercellular spaces. Casparian strips are generally absent. The endodermal cells often contain conspicuous starch grains as food reserve. Therefore, the stem endodermis is also called **starch sheath**.

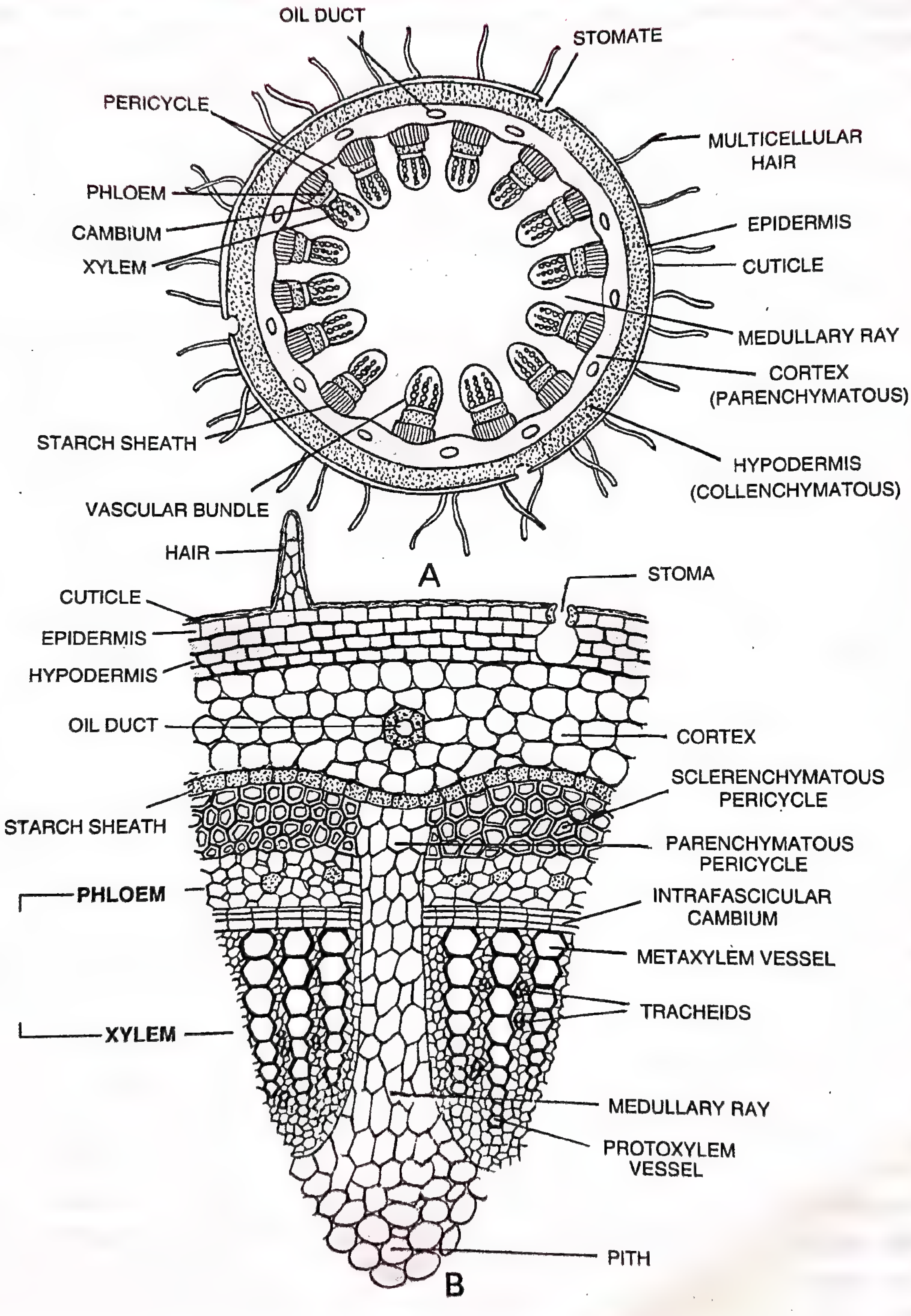


Fig. 6.26. A, T.S. Primary dicot stem of Sunflower (Diagrammatic); B, detailed structure of a part of T.S. stem of Sunflower.

5. **Pericycle.** It is few layered thick tissue. It lies inner to endodermis and **outside** the vascular strand. The pericycle is **heterogenous.** It is made up of both parenchyma and sclerenchyma fibres. Sclerenchyma lies on the outside of vascular bundles in the form of semicircular to semilunar patches called **bundle caps.** As the bundle caps are associated with phloem part of vascular bundles, the sclerenchymatous pericycle is also called **hard bast.** Parenchymatous pericycle is present outside medullary rays. In *Cucurbita,* pericycle is **homogeneous.** It is a completely sclerenchymatous wavy layer of 4–5 celled thickness. The sclerenchymatous pericycle provides mechanical strength to the young stem. The parenchymatous pericycle stores food.

6. **Vascular Strand.** The vascular strand is in the form of **eustele** or a **ring of vascular bundles** present around the central **pith** and inner to the **pericycle.** The vascular bundles are definite in number. They are obtusely wedge shaped. Each vascular bundle consists of **phloem** (primary) on the **outside**, **xylem** towards the **inner side** and strip of **cambium in** between the two. Phloem and xylem tissues lie on the **same radius.** Such vascular bundles are known as **conjoint** (with both phloem and xylem), **collateral** (phloem and xylem on the same radius) and **open** (with a strip of cambium in between phloem and xylem). Bicollateral open vascular bundles occur in the stem of *Cucurbita* and its relatives.

(a) **Phloem.** It lies towards the pericycle on the **outer** side of vascular bundle. Phloem consists of sieve tubes, companion cells, phloem parenchyma and some phloem fibres. The **companion cells** and **phloem parenchyma** are connected with sieve tubes through pits. They help in the **lateral flow** of the **organic food.** The **companion cells** also control the functions of the sieve tubes. The **sieve tubes** conduct organic food longitudinally.

(b) **Xylem.** It is **found towards** the **pith** or the **inner** portion of the vascular bundles. Xylem consists of two parts, smaller **protoxylem** (of narrow elements) and larger **metaxylem** (of broader elements). Protoxylem or first formed xylem lies at the tip of metaxylem towards the pith or centre of stem. Therefore, xylem is **endarch** (development centrifugal).

Xylem consists of **tracheids, vessels, xylem parenchyma** and **xylem fibres.** Out of these only the **xylem parenchyma** cells are living. They are smaller in size than the parenchyma cells found outside the bundles. Xylem parenchyma cells store food and help in the lateral conduction of the sap.

Vessels are present in the form of a few radial rows. They are angular in outline. The vessels of the **protoxylem** region are **smaller** and possess **annular** or **spiral** thickenings. These thickenings make the protoxylem vessels elastic and capable of stretching during the elongation of stem. The vessels of **metaxylem** have **pitted** thickenings.

Tracheids are present in between and around the radial rows of vessels especially of the metaxylem region. **Xylem fibres** lie scattered amongst the tracheids. The vessels, tracheids and xylem fibres, all provide **mechanical strength** to the stem. However, the most important function of xylem is the **conduction of water** and **mineral substances.** This is carried out by two tracheary elements, vessels and tracheids.

(c) **Cambium.** It is the leftout portion of procambium. Cambium is in the form of a **narrow strip** of primary **meristematic** cells that lie between the phloem and the xylem of a vascular bundle. It is called **intrafascicular** or **fascicular cambium.** Cambial cells are thin-walled fusiform cells which appear rectangular in transverse section.

Cambium helps in increasing the girth of stem by producing **secondary phloem** towards outside and **secondary xylem** towards the inner side (secondary growth).

7. **Medullary** or **Pith Rays**. They are the radial strips of parenchyma which are present **between** adjacent vascular bundles. The medullary rays **connect** the **pith** with **pericycle** and **cortex**. The ray cells are larger than cortical cells. They are polygonal in outline. Intercellular spaces are small. Ray cells make intimate contact with the conducting cells of both phloem and xylem through pits.

The medullary rays help in the **radial conduction** of food and water. They also transport **gases** from pith to cortex and *vice versa*.

8. **Pith** or **Medulla**. It forms the **centre** of the stem. The pith is made up of polygonal oval or rounded parenchyma cells which enclose intercellular spaces. The pith cells store food. In some dicots, the central part of the pith disintegrates to produce a cavity (pith cavity), *e.g.*, *Cucurbita*.

MONOCOT STEM (Fig. 6.27)

A monocot stem **lacks** secondary growth. It, therefore, possesses only the primary permanent tissues. The various tissues, unlike a dicot stem, are **not arranged** in concentric rings. The stem can be **solid** (*e.g.*, Maize, *Asparagus*) or **fistular** (with central cavity, *e.g.*, grass). A typical monocot stem (*e.g.*, Maize) consists of the following tissues (Fig. 6.27):

1. **Epidermis**. It is the outermost layer of the stem which is made up of compactly arranged transparent, elongated and rectangular—barrel-shaped living parenchyma cells. The outer walls of epidermal cells possess deposition of silica and cutin. A separate layer of **cuticle** also occurs on the outside. The cuticle and cutinised epidermal cells prevent the evaporation of water from the stem. Silica provides stiffness. Hair are usually absent. At places the epidermis possesses **stomata** for gaseous exchange. Each stomate has two dumb-bell shaped guard cells.

2. **Hypodermis**. It is 2–3 layered thick and lies below the epidermis. Hypodermis is made up of thick walled lignified **sclerenchyma fibres**. It acts as heat screen and provides rigidity and mechanical strength to the stem.

3. **Ground Tissue**. It does not show distinction into cortex, endodermis, pericycle, pith and pith rays. The ground tissue is parenchymatous and occupies the whole stem interior. In the stem of Maize the cells are small and angular towards the hypodermis but become large and oval in the inner region. The ground tissue **stores food**. Some of the outer cells may also synthesize food due to the presence of chloroplasts in them (chlorenchymatous cells). Abundant intercellular spaces are present in the ground tissue. These spaces communicate with exterior through the stomata present in the epidermis.

4. **Vascular Strand**. The vascular strand is in the form of **atactostele** where a large **number of vascular bundles** lie scattered throughout the ground tissue. Vascular bundles are smaller but more numerous towards the outside than towards the centre.

The vascular bundles (Fig. 6.27 B,C) are oval or rounded in outline. They contain **both phloem** and **xylem**. Phloem lies towards the **outside** and the xylem on the **inner side**. **Cambium is absent** as the whole procambium is consumed in the formation of vascular tissues. The vascular bundles are, therefore, **conjoint, collateral** but **closed**. Each vascular bundle is surrounded by a sheath of sclerenchyma known as **bundle sheath**. The bundle sheath is more developed on the outer and the inner sides. Hypodermis and bundle sheaths coalesce in some of the outer vascular bundles. A bundle sheath is absent in *Asparagus*.

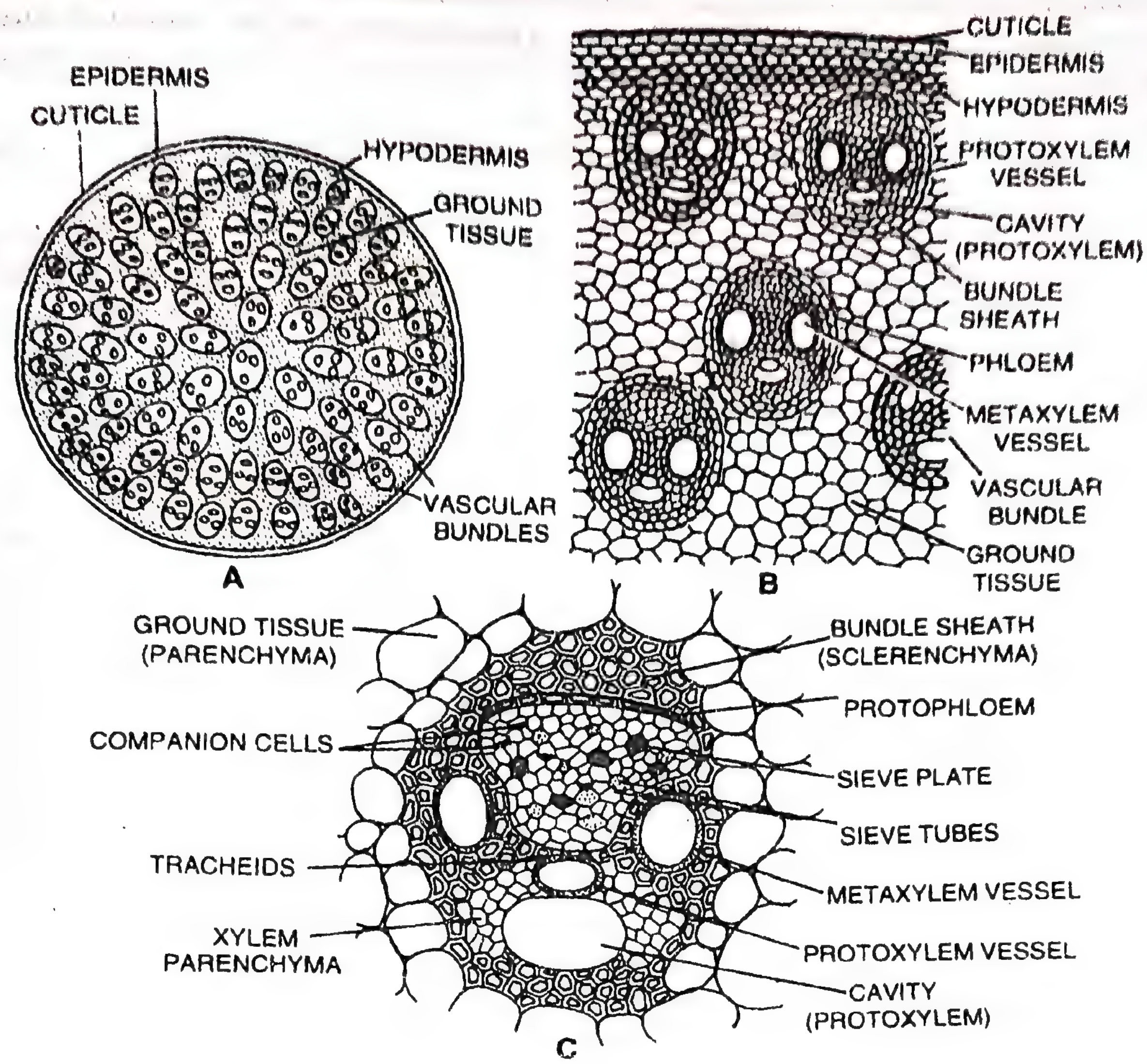


Fig. 6.27. T.S. Monocot stem of Maize (*Zea mays*). A, diagrammatic; B, part of T.S.; C, vascular bundle.

Phloem consists of sieve tubes, companion cells and a few phloem fibres. *Phloem parenchyma is absent*. The sieve tubes conduct organic food. In Maize, phloem is distinguished into outer **protophloem** and inner **metaphloem**. The protophloem gets crushed in the later stages.

Xylem is in the form of letter Y. It is **endarch**, *i.e.*, protoxylem lies towards the centre of the stem. Xylem is made up of vessels, tracheids, xylem parenchyma and a few xylem fibres. **Metaxylem** generally consists of two large oval or rounded vessels lying at the **upper** two angles of xylem. The metaxylem vessels have **pitted** walls. The two vessels are connected with each other by polygonal tracheids having pitted thickenings.

Protoxylem has a few (2–3) **small oval** vessels. They lie at **lower** angle of xylem. The vessels of protoxylem show **spiral** and **annular** thicknenings. Xylem parenchyma and a few fibres are found just outside them.

Some of the protoxylem vessels and xylem parenchyma cells dissolve or separate during the rapid growth of the stem to form a cavity called **protoxylem cavity** or **lacuna** (absent

in *Asparagus*). The protoxylem cavity of Maize is **schizo-lysigenous** in origin. It generally stores water. The tracheids and vessels help in the conduction of sap as well as mechanical support. In Maize the protoxylem cavity and protophloem can be absent in the smaller vascular bundles.

Differences between Dicot and Monocot Stems

Dicot Stem	*Monocot Stem*
1. Stomata have kidney-shaped guard cells.	1. Stomata usually possess dumb bell-shaped guard cells.
2. The hypodermis is made up of collenchyma which may be green.	2. The hypodermis is formed of non-green sclerenchyma fibres.
3. The internal tissues are arranged in concentric layers.	3. The concentric arrangement of tissues is absent.
4. The ground tissue is differentiated into cortex, endodermis, pericycle, pith, etc.	4. The ground tissue is a mass of similar cells.
5. The stem is almost always solid.	5. The stem is generally hollow in the center (exception Maize).
6. The vascular bundles are arranged in ring around the pith.	6. The vascular bundles are scattered throughout the ground tissue.
7. Medullary rays occur in between vascular bundles for radial conduction.	7. Medullary rays are absent.
8. The vascular bundles are fewer in number and are of similar size.	8. The vascular bundles are numerous and are of different sizes— smaller towards the outside and larger towards the centre.
9. The vascular bundles are wedge-shaped in outline.	9. They are oval or rounded in outline.
10. No bundle sheath is present on the outside of a vascular bundle.	10. A sclerenchymatous bundle sheath is generally present on the outside of each vascular bundle.
11. The vascular bundles are open due to the presence of cambium in between phloem and xylem.	11. The vascular bundles are closed.
12. Phloem parenchyma is present in the phloem alongwith other elements.	12. Phloem parenchyma is absent.
13. The stem shows secondary growth due to the formation of secondary vascular tissues and periderm.	13. Secondary growth is usually absent.
14. Vessels are polygonal in outline.	14. Vessels are oval or rounded.
15. Vessels are usually arranged in chains or rows.	15. Vessels are arranged in a Y-shaped manner.
16. Metaxylem vessels are generally numerous.	16. Metaxylem vessels are a few in number.
17. A cavity is not found in the vascular tissues.	17. A cavity containing water is found in vascular bundle by the dissolution or separation of some protoxylem vessels and parenchyma cells lying nearby.
18. The older vascular tissues stop functioning after some time. They are replaced by younger vascular tissues.	18. The first formed vascular tissues continue functioning throughout the life of the plant.
19. The stem shows increase in diameter with age.	19. There is little increase in diameter with age.
20. Old stem is covered by a corky bark.	20. No additional structure is produced for protection of old stem. Persistent leaf bases occur in some.

Differences between Stem and Root

Stem	*Root*
A. MORPHOLOGY	
1. Stem arises from the plumule of embryo.	1. Root arises from the radicle of the embryo. It may also arise from any other part of the plant.
2. Stems are generally green, at least in the young state.	2. Roots are non-green.
3. It generally forms the ascending or above ground part of the plant (several exceptions).	3. The root is generally the descending or underground part of the plant (several exceptions).
4. Stem is differentiated into nodes and internodes.	4. Nodes and internodes are absent.
5. Stem bears leaves and buds on its nodes.	5. Both leaves and buds are absent.
6. A root cap or any other equivalent structure is absent.	6. A root cap is formed at the tip of the root.
7. Stem is generally positively phototropic, negatively hydrotropic and negatively geotropic.	7. Root is positively geotropic and hydrotropic, neutral or negatively phototropic.
8. The growing point of the stem is protected by young leaves.	8. The growing point of the root is protected by root cap.
9. The tip of stem possesses terminal bud.	9. A terminal bud is absent.
10. Growing point is terminal.	10. Growing point is subterminal.
11. Stem generally possesses multicellular hairs.	11. Root hairs are always unicellular.
12. Stem hairs are found all over the stem.	12. Root hairs are restricted to a particular area called root hair zone.
13. Stem hairs prevent the evaporation of water from the surface.	13. Root hairs help in the absorption of water from the soil.
14. The branches are exogenous or superficial in origin.	14. The root branches are endogenous or deep seated.
15. Stem branches develop from nodes.	15. Root branches do not arise from specific areas.
16. Stem branches are formed from axillary buds.	16. Root branches do not arise from buds.
B. ANATOMY	
1. Cells of the epidermis have cutinised outer walls. A separate non-cellular layer of cuticle may also be formed on the outside.	1. Functional epiblema is without any cuticle or cutinised outer walls.
2. Epidermis is protective in function.	2. Young epiblema is absorptive in function.
3. Stomata are found on the stem.	3. Stomata are always absent.
4. Stem hairs usually do not arise as outgrowths of epidermal cells.	4. Root hairs are tubular outgrowths of the epidermal cells.
5. A collenchymatous or sclerenchymatous hypodermis is found below the epidermis.	5. Hypodermis is usually absent in young roots. A thick-walled exodermis is present in some cases.
6. A few outer cells of the ground tissues may contain chloroplasts.	6. Chloroplasts are almost invariably absent.
7. Cortex is narrow.	7. Cortex is broad.
8. Endodermis is not conspicuous.	8. Endodermis is conspicuous.
9. Pericycle, when present, is usually multi-layered.	9. Pericycle is commonly 1-2 layered.

10. Pericycle does not take part in secondary growth.	10. Pericycle is active in the formation of root branches and development of secondary growth.
11. Vascular bundles are conjoint and collateral.	11. Vascular bundles are radial, *i.e.*, phloem and xylem bundles are separate and are found on different radii.
12. Secondary vascular growth, when present, is by cambium which is both intrafascicular and interfascicular.	12. Secondary vascular growth when present arises from conjunctive parenchyma and pericycle.
13. Xylem is endarch.	13. Xylem is exarch.
14. Xylem and phloem contain fibres.	14. Fibres are generally absent.
15. The chief functions of the stem are storage, conduction and photosynthesis.	15. The chief functions of the root are absorption of water and mineral salts and anchorage.

SECONDARY GROWTH IN DICOT STEM

Primary growth produces growth in length and development of lateral appendages. Secondary growth is the formation of secondary tissues from lateral meristems. It increases the diameter of the stem. In woody plants, secondary tissues constitute the bulk of the plant. They take part in providing protection, support and conduction of water and nutrients. Secondary tissues are formed by two types of lateral meristems, **vascular cambium** and **cork cambium** or **phellogen**. **Vascular cambium** produces **secondary vascular tissues** while phellogen forms **periderm**. Secondary growth occurs in perennial gymnosperms and dicots such as **trees** and **shrubs**. It is also found in the **woody stems** of some **herbs**. In such cases, the secondary growth is equivalent to one annual ring, *e.g.*, Sunflower.

A. Formation of Secondary Vascular Tissues. They are formed by the **vascular cambium**. Vascular cambium is produced by two types of meristems, **fascicular** or **intrafascicular** and **interfascicular** cambium. Intrafascicular cambium is a primary meristem which occurs as strips in vascular bundles. Interfascicular cambium arises secondarily from the cells of medullary rays which occur at the level of intrafascicular strips. These two types of meristematic tissues get connected to form a ring of **vascular cambium**. Vascular cambium is truely single layered but appears to be a few layers (2–5) in thickness due to presence of its immediate derivatives. Cells of vascular cambium divide periclinally both on the outer and inner sides (bipolar divisions) to form secondary permanent tissues.

The cells of vascular cambium are of two types, elongated spindle-shaped **fusiform initials** and shorter isodiametric **ray initials** (Fig. 6.29). Both appear rectangular in T.S. Ray initials give rise to **vascular rays**. Fusiform initials divide to form **secondary phloem** on the outer side and **secondary xylem** on the inner side (Fig. 6.28 B). With the formation of secondary xylem on the inner side, the vascular cambium moves gradually to the outside by adding new cells. The phenomenon is called **dilation**. New ray cells are also added. They form additional rays every year (Fig. 6.28 D). The vascular cambium undergoes two types of divisions— **additive** (periclinal divisions for formation of secondary tissues) and **multiplicative** (anticlinal divisions for dilation). Ray initials produce **radial system** (= horizontal or transverse system) while fusiform initials form axial system (= vertical system) of secondary vascular tissues.

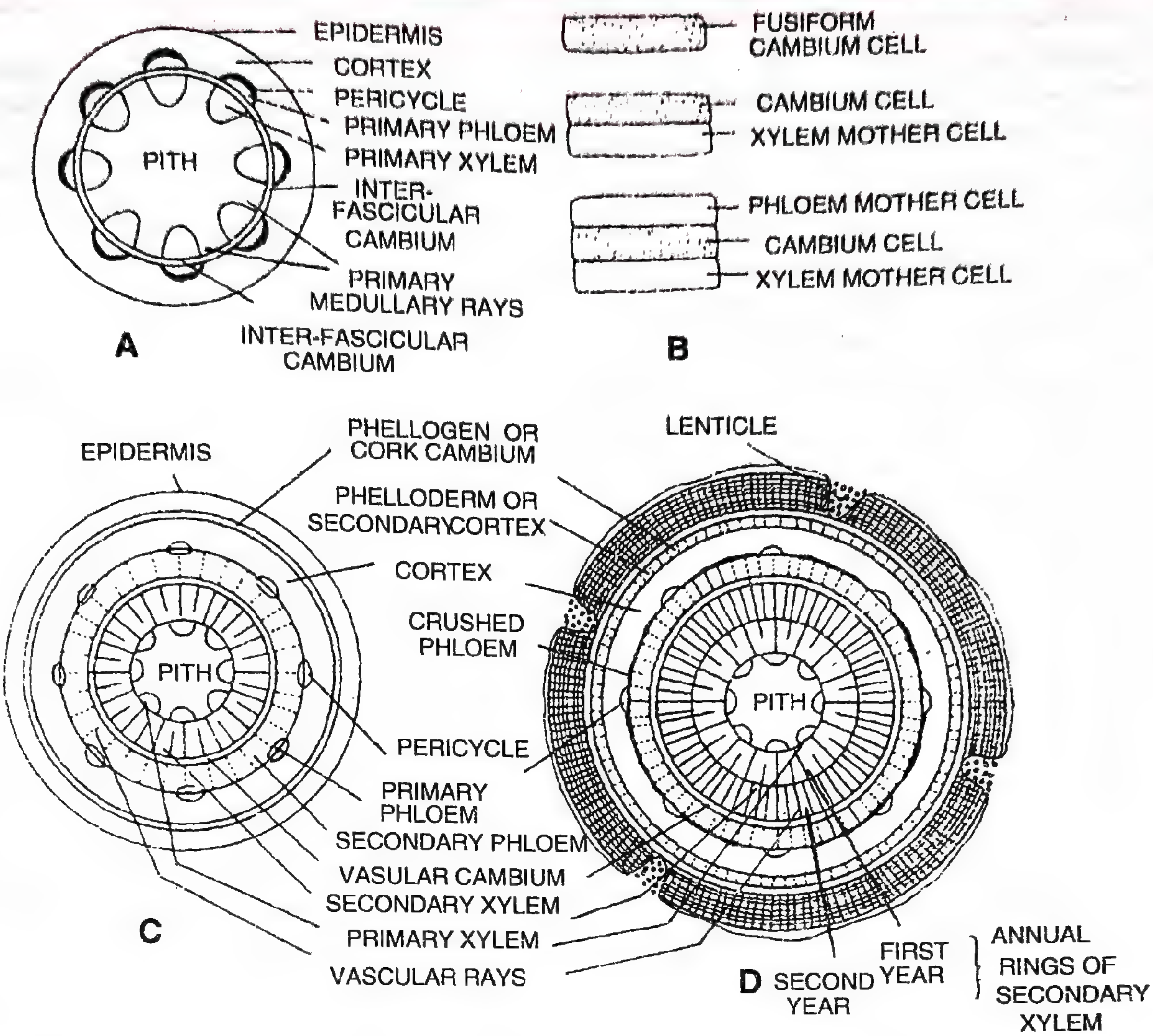


Fig. 6.28. A, complete ring of vascular cambium formed by strips of intrafascicular cambium and inter-fascicular cambium. B, formation of secondary vascular tissue mother cells; C, the beginning of secondary growth (mostly made up of secondary vascular tissues) of dicot stem (diagrammatic); D, two-year stage of secondary growth of a dicot stem.

Differences between Fascicular Cambium and Interfascicular Cambium

Fascicular (Intrafascicular) Cambium	*Interfascicular Cambium*
1. It is a primary meristem.	1. It is a secondary meristem.
2. Fascicular cambium is present even in the primary stem.	2. Interfascicular cambium develops only when secondary growth is to occur.
3. Fascicular or intrafascicular cambium lies inside vascular bundles of the stem.	3. Interfascicular cambium is formed in between the vascular bundles.
4. It is derived from procambium of stem apical meristem.	4. It develops from permanent cells of medullary rays through the process of dedifferentiation.

1. **Vascular Rays.** The vascular rays or **secondary medullary rays** are rows of radially arranged cells which are formed in the secondary vascular tissues. They are a few cells in height. Depending upon their breadth, the vascular rays are **uniseriate** (one cell in breadth) or **multiseriate** (two or more cells in breadth). Vascular rays may be **homocellular**

(having one type of cells) or **heterocellular** (with more than one type of cells). The cells of the vascular rays enclose intercellular spaces. The part of the vascular ray present in the secondary xylem is called **wood** or **xylem** ray while the part present in the secondary phloem is known as **phloem ray**.

The vascular rays conduct water and organic food and permit diffusion of gases in the radial direction. Besides, their cells store food.

2. **Secondary Phloem (Bast).** It forms a narrow circle on the outer side of vascular cambium. Secondary phloem does not grow in thickness because the primary and the older secondary phloem present on the outer side gets crushed with the development of new functional phloem (Fig. 6.28 D). Therefore, rings (annual rings) are not produced in secondary phloem. The crushed or non-functioning phloem may, however, have fibres and sclereids.

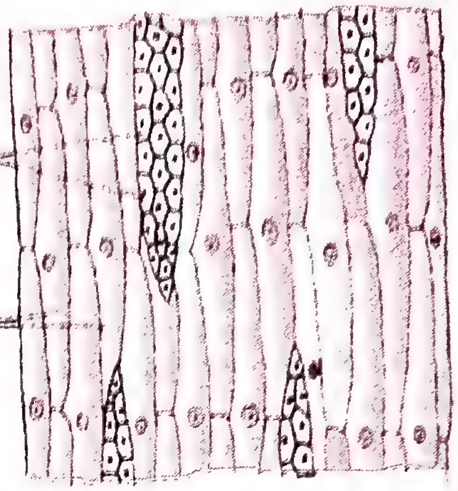


Fig. 6.29. L.S. Vascular cambium showing fusiform and ray initials.

Secondary phloem is made up of the same type of cells as are found in the primary phloem (metaphloem)— sieve tubes, companion cells, phloem fibres and phloem parenchyma. Phloem parenchyma is of two types— **axial** phloem parenchyma made up of longitudinally arranged cells and phloem **ray** parenchyma formed of radially arranged parenchyma cells that constitute the part of the vascular ray present in the phloem (Fig. 6.31). Elements of secondary phloem show a more regular arrangement. Sieve tubes are comparatively more numerous but are shorter and broader. Sclerenchyma fibres occur either in patches or bands. Sclereids are found in many cases. In such cases secondary phloem is differentiated into **soft bast** (secondary phloem without fibres) and **hard bast** (part of phloem with abundant fibres).

Differences between Primary Phloem and Secondary Phloem

Primary Phloem	*Secondary Phloem*
1. It is formed from procambium of apical meristem.	1. Secondary phloem develops from a lateral meristem called vascular cambium.
2. It is found in the primary plant body of all vascular plants.	2. It is found only during secondary growth of dicots and gymnosperms with the exception of annuals.
3. Primary phloem occurs in all types of organs.	3. Secondary phloem is restricted to stems and roots of perennial dicots and gymnosperms.
4. It occurs towards the periphery.	4. It is formed inner to the primary phloem.
5. Primary phloem is differentiated into protophloem and metaphloem.	5. There is no such distinction.
6. A radial system is absent.	6. It is traversed by radial system of phloem rays.
7. Phloem fibres are fewer. They are restricted to outer part.	7. Phloem fibres are more abundant. They commonly occur in patches or bands.

8. Primary phloem shows an irregular arrangement of various types of cells.	8. Secondary phloem has a more regular arrangement.
9. Sieve tubes are comparatively fewer.	9. Sieve tubes are comparatively more numerous.
10. Sieve tubes are longer and narrower.	10. Sieve tubes are shorter but wider.
11. Phloem parenchyma is less abundant.	11. It is more abundant.
12. Crystals and other depositions are rare.	12. The cells often contain crystals and depositions of various substances.
13. Sclereids are usually absent.	13. Sclereids are formed in the secondary phloem of several plants.

3. **Secondary Xylem.** It forms the bulk of the stem and is commonly called wood. The secondary xylem consists of vessels, tracheids (both tracheary elements), wood fibres and wood parenchyma. Wood parenchyma may contain tannins and crystals besides storing food. It is of two types— **axial** parenchyma cells arranged longitudinally and **radial** ray parenchyma cells arranged in radial or horizontal fashion. The latter is part of vascular ray present in secondary xylem. Secondary xylem does not show distinction into protoxylem and metaxylem elements. Therefore, vessels and tracheids with annular and spiral thickenings are absent. The tracheary elements of secondary xylem are similar to those of metaxylem of the primary xylem with minor differences. They are comparatively shorter and more thick-walled. Pitted thickenings are more common. Fibres are abundant.

Width of secondary xylem grows with the age of the plant. The primary xylem persists as conical projection on its inner side. Pith may become narrow and ultimately get crushed. The yearly growth of secondary xylem is distinct in the areas which experience **two seasons**, one **favourable** (spring or rainy season) and the other **unfavourable** (autumn, winter or dry summer). In favourable season the temperature is optimum. There is a good sunshine and humidity. At this time the newaly formed leaves produce hormones which stimulate cambial activity. The activity decreases and stops towards the approach of unfavourable season. Hence the annual or yearly growth appears in the form of distinct rings which are called **annual rings** (Fig. 6.30). Annual rings are formed due to sequence of rapid growth (favourable season, *e.g.*, spring), slow growth (before the onset of unfavourable period, *e.g.*, autumn) and no growth (unfavourable season, *e.g.*, winter). Annual rings are not distinct in tropical areas which do not have long dry periods.

Fig. 6.30. Part of T.S. old stem showing annual rings.

Annual Rings (Growth Rings). It is the wood formed in a single year. It consists of two types of wood, **spring wood** and **autumn wood** (Fig. 6.31). The **spring** or **early wood** is **much wider** than the **autumn** or **late wood**. It is Lighter in colour and of lower density. Spring wood consists of **larger** and **wider** xylem elements. The **autumn** or late wood is dark coloured and of higher density. It contains compactly arranged **smaller** and **narrower** elements which have comparatively thicker walls. In autumn wood, tracheids and fibres are more abundant than those found in the spring wood.

The **transition** from spring to autumn wood in an annual ring is **gradual** but the transition from autumn wood to the spring wood of the next year is **sudden**. Therefore, each year's growth is quite distinct. The number of annual rings corresponds to the age of that part of the stem. (They can be counted by **increment borer**). Besides giving the age of the plant, the annual rings also give some clue about the climatic conditions of the past through

which the plant has passed. **Dendrochronology** is the science of counting and analysing annual growth rings of trees.

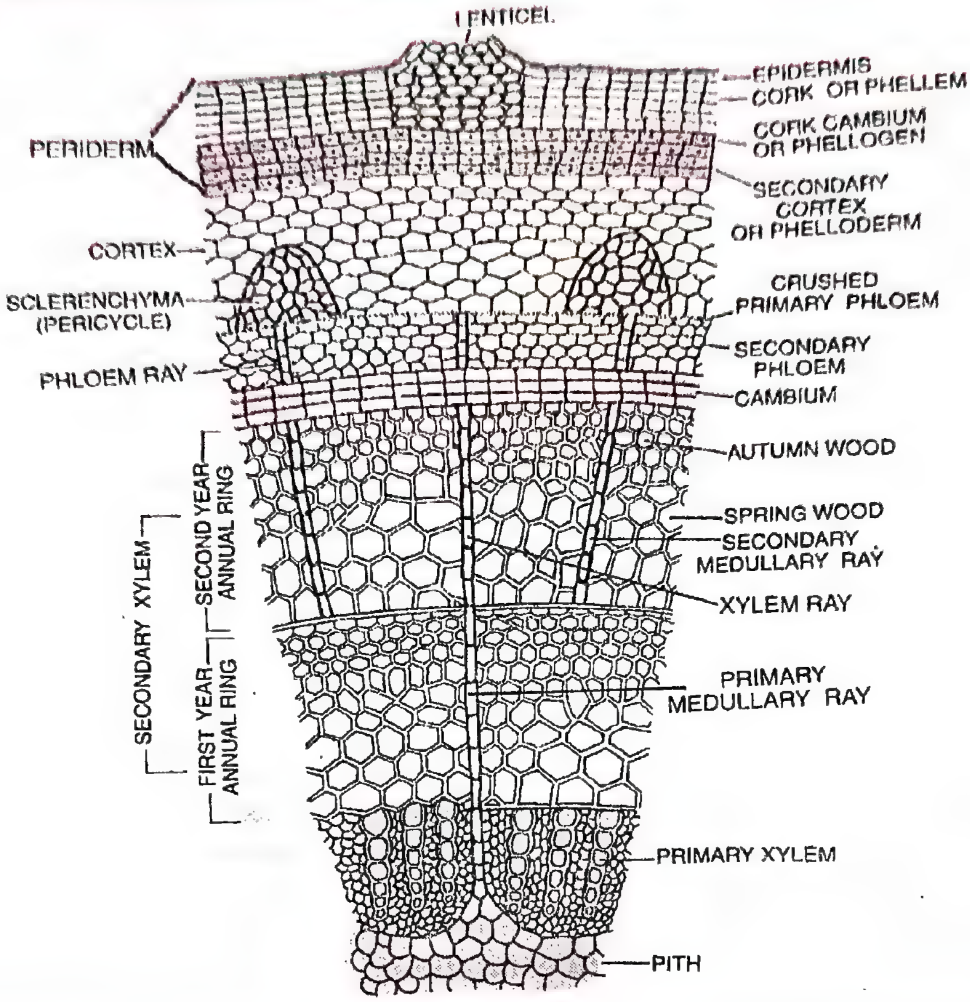


Fig. 6.31. Part of detailed structure of transverse section of two year old dicot stem showing secondary growth.

Differences between Spring Wood and Autumn Wood

Spring Wood (Early Wood)	*Autumn Wood* (Late Wood)
1. It is produced during the favourable period of the year.	1. It is formed towards the close of the active growing period of the year just before the arrival of unfavourable period.
2. Spring wood constitutes the major part of the annual ring.	2. Autumn wood forms a narrow strip in the annual ring.
3. It occurs in the beginning of an annual ring.	3. Autumn wood occurs at the end of an annual ring.
4. It contains larger and wider elements.	4. Autumn wood is formed of smaller and narrower elements.
5. Fibres are fewer.	5. Fibres are abundant.
6. The wood is lighter in colour.	6. The wood is darker.
7. The tracheary elements are comparatively less thickened.	7. The tracheary elements are comparatively more thickened.
8. It has lower density.	8. It has higher density.

Softwood and Hardwood. Softwood is the technical name of gymnosperm wood because it is devoid of vessels. Several of the softwoods are very easy to work with (*e.g., Cedrus, Pinus* species). However, all of them are not 'soft'. The softness depends upon the content of fibres and vascular rays. 90–95% of wood is made of tracheids and fibres. Vascular rays constitute 5–10% of the wood.

Hardwood is the name of dicot wood which possesses abundant vessels. Due to the presence of vessels, the hardwoods are also called **porous woods.** In *Cassia fistula* and *Dalbergia sisso* the vessels are comparatively very broad in the spring wood while they are quite narrow in the autumn wood. Such a secondary xylem or wood is called **ring porous.** In others (*e.g., Syzygium cumini*) larger sized vessels are distributed throughout spring wood and autumn wood. This type of secondary xylem or wood is known as **diffuse porous.** Ring porous wood is more advanced than diffuse porous wood as it provides for better translocation when the requirement of the plant is high.

Differences between Softwood and Hardwood

Softwood	*Hardwood*
1. It is the name of gymnosperm wood.	1. Hardwood is the name of dicot wood.
2. The wood is devoid of vessels. It is, therefore, also called **nonporous wood.**	2. The wood contains vessels. It is, therefore, called **porous wood.**
3. The content of tracheids can be 90-95%.	3. The content of the tracheids is very low (less than 5%).
4. Wood or xylem fibres are fewer.	4. Wood or xylem fibres are abundant.
5. The wood is easy to work with.	5. The wood is comparatively difficult to work with.

Sapwood and Heartwood. The wood of the older stems (*Dalbergia, Acacia*) gets differentiated into two zones, the outer **light** coloured and functional **sapwood** or **alburnum** and the inner **darker** and nonfunctional **heartwood** or **duramen** (Fig. 6.33). The tracheids and vessels of the heart wood get plugged by the ingrowth of the adjacent parenchyma cells into their cavities through the pits. These ingrowths are called **tyloses** (Fig. 6.32).

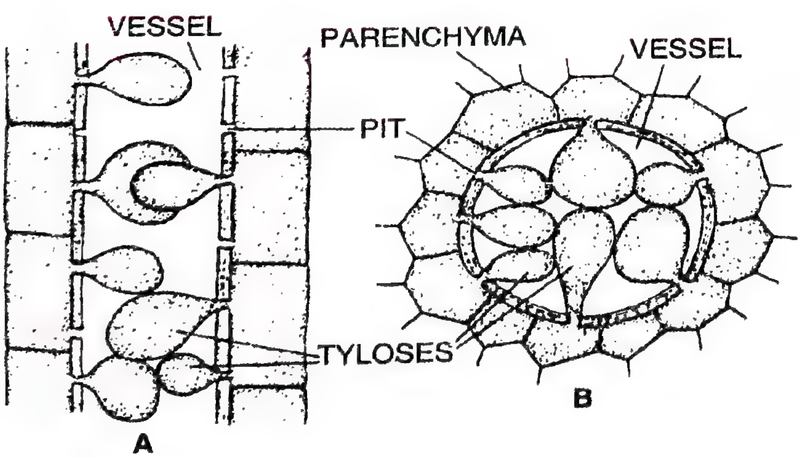


Fig. 6.32. Formation of tyloses in heartwood.
A, L.S. vessel showing tyloses.
B, T.S. vessel showing tyloses.

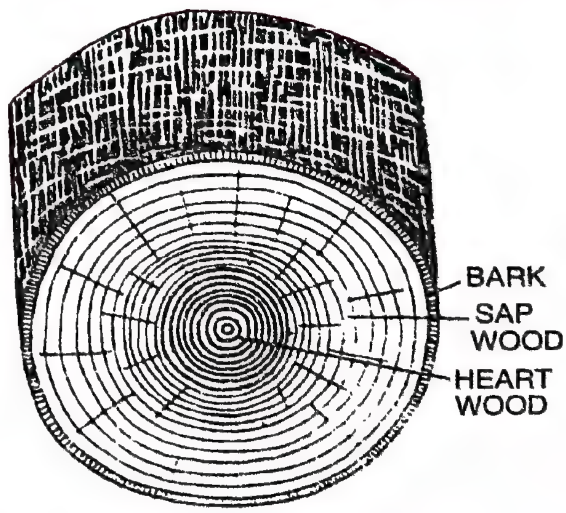


Fig. 6.33. Sapwood and heartwood in T.S. of trunk.

Ultimately, the parenchyma cells become lignified and dead. Various types of plant products like **oils, resins, gums, aromatic substances, essential oils** and **tannins** are deposited in the cells of the heartwood. These substances are collectively called **extractives**. They provide **colour** to the heartwood. They are also **antiseptic**. The heartwood is, therefore, stronger and more durable than the sapwood. It is resistant to attack of insects and microbes. Heart wood is commercial source of Cutch (*Acacia catechu*), Haematoxylin (*Haematoxylon campechianum*), Brasilin (*Caesalpinia sappan*) and Santalin (*Pterocarpus santalinus*). Heartwood is, however, liable to be attacked by wood rotting fungi. Hollow tree trunks are due to their activity.

Differences between Sapwood or Alburnum and Heartwood or Duramen

Sapwood (Alburnum)	*Heartwood* (Duramen)
1. It is outer wood of an old stem.	1. It is the central wood of an old stem.
2. It is light coloured.	2. Heartwood is dark coloured.
3. Living cells are present.	3. Living cells are absent.
4. Sapwood is the functional part of the secondary xylem or wood.	4. Heartwood is the nonfunctional part of secondary xylem.
5. The tracheary elements are not plugged by tyloses.	5. The tracheary elements are plugged by tyloses.
6. Tracheary elements do not possess any deposition in their lumen.	6. Tracheary elements have deposition of tannins, resins, gums, etc.
7. Sapwood or alburnum is lighter.	7. Heartwood is heavier.
8. It is less durable because it is susceptible to attack by pathogens and insects.	8. It is more durable due to its little susceptibility to the attack of pathogens and insects.

Differences between Primary and Secondary Xylem

Primary xylem	*Secondary xylem*
1. It is formed from procambium of apical meristem.	1. Secondary xylem is produced from lateral meristem, called vascular cambium.
2. It occurs in the primary plant body of all vascular plants.	2. Secondary xylem is formed during secondary growth only.
3. Primary xylem is found in all types of organs.	3. It is restricted to stems and roots of only perennial dicots and gymnosperms.
4. It occurs towards the center.	4. It occurs towards the outer side of primary xylem.
5. Primary xylem occurs in patches.	5. Secondary xylem forms a cylinder.
6. The xylem is differentiated into two parts, protoxylem and metaxylem.	6. There is no such distinction.
7. A radial system is absent.	7. It is traversed by a radial system of xylem rays.
8. Annual rings are absent.	8. It may show annual rings.
9. There is no distinction into sapwood and heartwood.	9. A distinction into sapwood and heartwood is found in large woody plants.
10. Fibres are few or absent.	10. Fibres are generally abundant.
11. The tracheids and vessels are long and comparatively less thick-walled.	11. The tracheids and vessels are comparatively shorter and more thick-walled.
12. All types of thickenings can occur in tracheary elements.	12. Usually pitted thickenings occur in the tracheary elements.
13. Tyloses are usually absent.	13. The vessels and tracheids of older xylem get blocked by the development of tyloses.

B. Formation of Periderm. In order to provide for increase in girth and prevent harm on the rupturing of the outer ground tissues due to the formation of secondary vascular tissues, dicot stems produce a **cork cambium** or **phellogen** in the outer cortical cells. Rarely it may arise from the epidermis (*e.g.*, Teak, Oleander), hypodermis (*e.g.*, Pear) or phloem parenchyma.

Phellogen cells divide on both the outer side as well as the inner side (bipolar) to form secondary tissues. The **secondary tissue** produced on the **inner side** of the phellogen is parenchymatous or collenchymatous. It is called **secondary cortex** or **phelloderm**. Its cells show radial arrangement.

Phellogen produces **cork** or **phellem** on the outer side. It consists of dead and compactly arranged rectangular cells that possess suberised cell walls. The cork cells contain tannins. Hence, they appear brown or dark brown in colour. The cork cells of some plants are filled with air *e.g.*, *Quercus suber* (Cork Oak or Bottle Cork). The phelloderm, phellogen and phellem together constitute the **periderm** (Fig. 6.34).

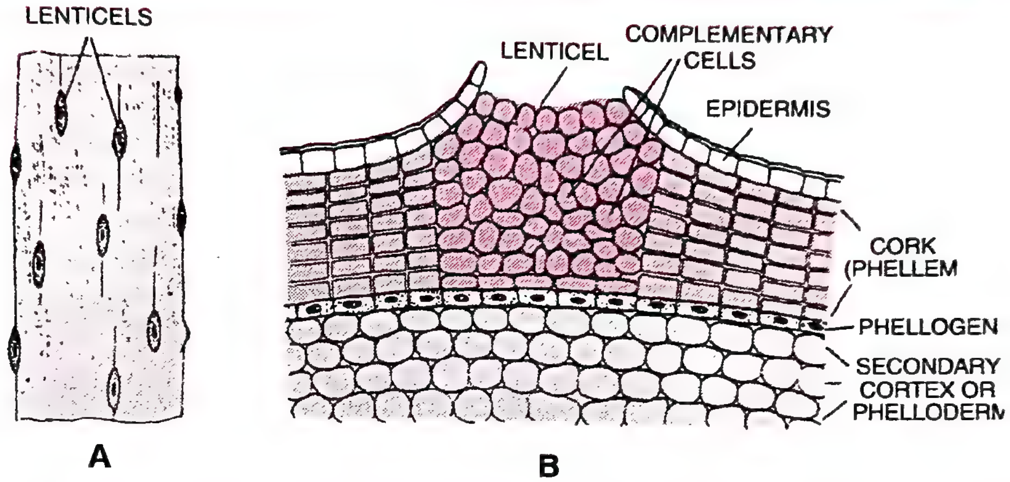


Fig. 6.34. Lenticels. A, external view of lenticels; B, T.S. lenticel.

Cork prevents the loss of water by evaporation. It also protects the interior against entry of harmful micro-organisms, mechanical injury and extremes of temperature. Cork is light, compressible, nonreactive and sufficiently resistant to fire. It is used as stopper for bottles, shock absorption and insulation. At places phellogen produces aerating pores instead of cork. These pores are called **lenticels**. Each lenticel is filled by a mass of somewhat loosely arranged suberised cells called **complementary cells**.

Lenticels. Lenticels are aerating pores in the bark of plants. They appear on the surface of the bark as raised scars containing oval, rounded or oblong depressions (Fig. 6.34 A). They occur in woody trees but not in climbers. Normally they are formed in areas with underlying rays for facilitating gas exchange. Lenticels may occur scattered or form longitudinal rows.

A lenticel is commonly produced beneath a former stomate or stoma of the epidermis. Its margin is raised and is formed by surrounding cork cells. The lenticel is filled up by loosely arranged thin walled rounded and suberised (*e.g.*, *Prunus*) or unsuberised cells called **complementary cells** (Fig. 6.34 B). They enclose intercellular spaces for gaseous exchange. The complementary cells are formed from loosely arranged phellogen cells and division of substomatal parenchyma cells. The suberised nature of complementary cells checks excessive evaporation of water.

In temperate plants the lenticels get closed during the winter by the formation of compactly arranged **closing cells** over the complementary cells.

Bark. In common language and economic botany, all the dead cells lying outside phellogen are collectively called bark*. The outer layers of the bark are being constantly peeled off on account of the formation of new secondary vascular tissues in the interior. The peeling of the bark may occur in sheets (sheets or ring bark, *e.g., Eucalyptus*) or in irregular strips (scaly bark). The scaly bark is formed when the phellogen arises in strips instead of rings, *e.g., Acacia* (*vern.* Kikar). Bark formed in early growing season is **early or soft bark.** The one formed towards end of growing season is **late** or **hard bark.**

Bark is insect repellent, decay proof, fire-proof and acts as a heat screen. Commercially it is employed in tanning (*e.g., Acacia*), drugs (*e.g., Cinchona*— quinine) or as spice (*e.g.,* Cannamon, *vern.* Dalchini). The cork of *Quercus suber* is employed in the manufacture of bottle stoppers, insulators, floats, sound proofing and linoleum.

Differences between Phellem and Phelloderm

Phellem	*Phelloderm*
1. Phellem or cork is a tissue formed on the outer side of phellogen or cork cambium.	1. Phelloderm or secondary cortex is produced on the inner side of phellogen.
2. It is composed of dead cells.	2. Phelloderm is made of living cells.
3. Phellem is protective in function.	3. Its cells take part in storage of food.
4. The cell walls become impermeable due to suberisation.	4. Suberisation is absent.
5. Phellem cells are filled with tannins.	5. Tannins are absent.
6. The cells are compactly arranged except for the presence of lenticels.	6. The cells enclose small intercellular spaces.
7. Phellogen is more active on the side of phellem, *i.e.,* more phellem is formed as compared to phelloderm.	7. Phellogen is less active on the side of phelloderm, *i.e.,* less phelloderm is formed as compared to phellem.
8. The outer part of the phellem is peeled off at intervals.	8. There is no loss of phelloderm.

Differences in Secondary Growth of Dicot Stems and Roots

Dicot Stem	*Dicot Root*
1. The vascular cambium is in the form of a circular strip or ring from the beginning.	1. The vascular cambium is a wavy band in the early stages of its activity.
2. The vascular cambium is made up of both primary (intra-fascicular) and secondary (interfascicular) strips of meristematic tissues.	2. The vascular cambium is secondary in origin. It is formed of conjunctive parenchyma and pericycle.
3. The vascular rays are narrow from the beginning.	3. Initially the vascular rays are wide and arise opposite the protoxylem points.
4. Ray initials are not grouped in a particular region.	4. Ray initials arise from the pericycle part of vascular cambium.
5. Annual rings are quite common.	5. Annual rings are absent.
6. Phellogen arises from a superficial layer of the cortex.	6. Phellogen generally originates from the pericycle.

* In anatomical and physiological usages bark includes all tissues outside the vascular cambium. It is then differentiated into outer bark or rhytidome (consisting of dead cells) and inner bark (of living cells, *i.e.,* periderm and secondary phloem).

Significance of Secondary Growth

1. Secondary growth adds to the girth of the plant. It provides support to increasing weight of the aerial growth.

2. Secondary growth produces a corky bark around the tree trunk that protects the interior from abrasion, heat, cold and infection.

3. It adds new conducting tissues for replacing old nonfunctioning ones as well as for meeting increased demand for long distance transport of sap and organic nutrients.

4. It provides a fire proof, insect proof and insulating cover around the older plant parts.

5. Commercial cork is a product of secondary growth. It is obtained from Quercus suber (Cork Oak).

6. Wood is a very important product of secondary growth. It represents secondary xylem.

Anomalous Secondary Growth

It is abnormal type of secondary growth that occurs in some arborescent monocots (*e.g., Dracaena, Yucca, Agave*) and storage roots (*e.g.*, Beet, Sweet Potato). In arborescent monocot stems, a secondary cambium grows in hypodermal region. The latter forms conjunctive tissue and patches of meristematic cells.

LEAF

Types of Leaves

Anatomically there can be three types of leaves— dorsiventral (bifacial), isobilateral (equifacial) and unifacial.

1. **Dorsiventral** (Bifacial). The leaves are commonly horizontal in orientation with distinct upper and lower surfaces. The upper surface is also called **inner, adaxial** or **ventral surface**. The lower surface is correspondingly called **outer, abaxial** or **dorsal surface**. Mesophyll is distinguishable into palisade and spongy tissues with palisade usually restricted to the upper side. Most of the **dicotyledonous leaves are dorsiventral**.

2. **Isobilateral** (Equifacial). The leaf is placed in such a way that both its surfaces receive equal amount of sunlight. A distinction into upper and lower surfaces is absent. Mesophyll is usually indistinguishable (or palisade tissue is present in equal amount on both the sides). Most of the **monocotyledonous leaves are isobilateral**.

3. **Unifacial**. A distinction into upper and lower surfaces is absent. The leaves are generally cylindrical, *e.g.*, Onion.

Dorsiventral Mesophytic Leaf

The upper or adaxial surface which faces the sun is darker than the lower or abaxial surface. The different parts are (Fig. 6.35) :

1. **Upper or Adaxial Epidermis**. It consists of a single layer of tightly packed rectangular-barrel shaped transparent parenchymatous cells which are devoid of chloroplasts. The inner and the radial walls of the epidermal cells are thin. The outer walls are cutinised. A distinct layer of **cuticle** lies on the outside of the epidermis. The cuticle prevents excessive transpiration, helps bind epidermal cells and protects them from mechanical injury.

Hair may occur here and there. They are also covered over by a layer of cuticle. Mesophytic leaves may have stomata in the upper epidermis.

2. **Lower or Abaxial Epidermis**. It bounds the leaf on the lower surface. The abaxial epidermis consists of a single layer of compactly arranged rectangular transparent parenchymatous cells. Their outer or lower walls are cutinised. A distinct layer of **cuticle** is also

present. The cuticle is, however, less developed than at the adaxial epidermis. Hair may occur here and there. They are usually multicellular and are covered by a layer of cuticle.

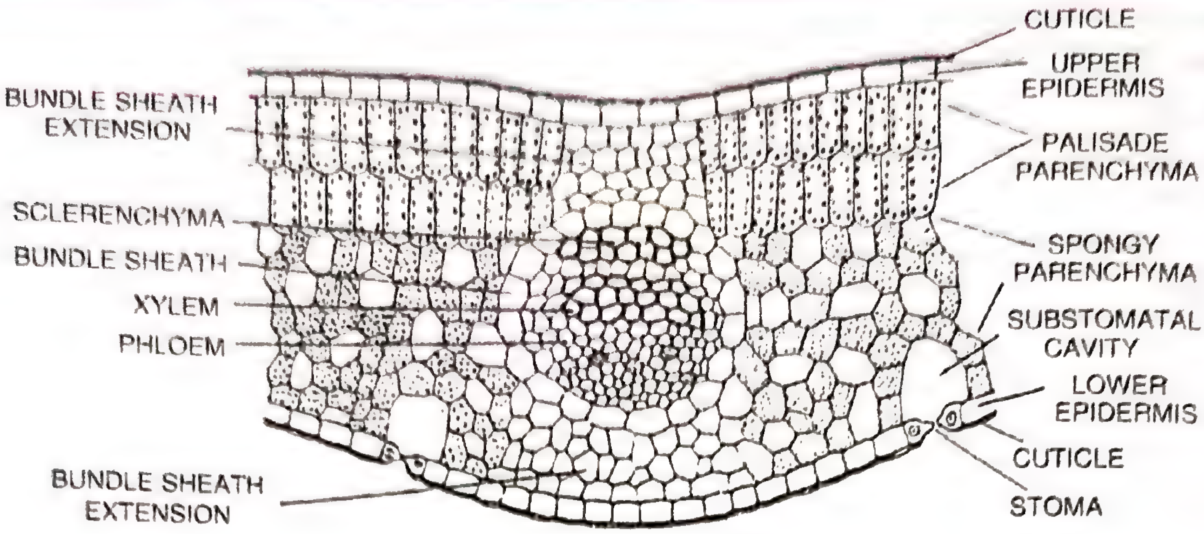


Fig. 6.35. V.S. dorsiventral leaf.

The abaxial epidermis contains a large number of pores called stomata or **stomates**. They lead internally into **substomatal cavities** or **chambers**. Substomatal cavities are connected with intercellular spaces of mesophyll. Each stoma or stomate has a narrow pore bounded and controlled by two small specialised kidney-shaped epidermal cells called **guard cells**. Their stomatal walls are thicker than the rest. Unlike other epidermal cells, the guard cells possess a few chloroplasts. The **opened stomata allow** the gaseous exchange between the interior of the leaf and the atmosphere. Incidentally this also causes transpiration. In many plants the two guard cells are associated with two or more specialized epidermal cells called **accessory** or **subsidiary cells** . Depending upon the distribution of stomata on the leaf surface, leaf is called **hypostomatic** (stomata only on lower surface) and **amphistomatic** (stomata on both surfaces).

The various functions of the epidermis are (i) protection of internal tissues (ii) exchange of gases through stomates (iii) loss of water vapours or transpiration through stomata (iv) reducing the rate of surface transpiration by the presence of cuticle (v) reducing the rate of transpiration by forming a stationary layer of air with the help of hair (vi) protection from microbial attack due to presence of cuticle.

3. **Mesophyll** (Gk. *meson*— middle, *phyllon*— leaf). The interior of the leaf, between the upper and the lower epidermis, contains veins and a parenchymatous green tissue or **chlorenchyma**. The chlorenchyma of leaf is known as **mesophyll**. Mesophyll is usually differentiated into two regions, upper **palisade** and lower **spongy**.

The **palisade parenchyma** or **palisade mesophyll** lies below the upper epidermis. It consists of 1-3 layers of vertically elongated, parallel and closely placed columnar or cylindrical cells. The long axes of these parenchyma cells lie at right angles to the surface of the leaf. The palisade mesophyll cells enclose a number of narrow intercellular spaces for exchange of gases. The compactness of palisade tissue is directly dependent upon the light intensity to which the leaf is exposed. The palisade parenchyma or palisade mesophyll cells are rich in discoid chloroplasts. They are, therefore, the main seat of **photosynthesis**.

The **spongy parenchyma** or **spongy mesophyll** lies between the lower epidermis and

the palisade parenchyma. Its cells may have various outlines like oval, rounded, irregular, lobed or branched. They have chloroplasts but fewer than present in the palisade parenchyma. The cell walls are thin but are suberised and unwettable in many species. The spongy cells are very loosely arranged except around the vascular bundles. They enclose large cavities or **intercellular spaces** which are connected with the atmosphere through the stomata. For this a large **substomatal cavity** lies below each stoma.

As the chloroplasts are more abundant in the compact palisade mesophyll cells than the loosely arranged spongy mesophyll cells, the upper surface of the leaf appears deeper green as compared to the lower surface.

4. **Vascular System or Strand.** It is made up of a number of vascular bundles of varying sizes depending upon the venation. The vascular bundles of ribs are thicker than those of lateral veins.

The vascular bundles are generally found at the boundary between the palisade and the spongy regions. Each vascular bundle is surrounded by a sheath of compactly arranged parenchyma cells called **bundle sheath**. The bundle sheath of the larger veins show parenchymatous **extensions** towards both the upper and lower sides.

The vascular bundles are almost rounded. They are **conjoint** and **collateral**, *i.e.*, they possess both phloem and xylem which lie on the same radius. **Xylem** lies towards the **upper** side of the leaf while **phloem** is found towards the **lower** surface. Xylem consists of vessels, tracheids, xylem parenchyma and a few xylem fibres. The **vessels** and **tracheids** conduct water and mineral salts besides providing mechanical support to the leaf. **Xylem parenchyma** stores food and allows lateral movement of water and mineral salts. **Xylem fibres**, when present, give additional strength to the leaf.

Phloem is made up of sieve tubes, companion cells and phloem parenchyma. Phloem fibres are rarely present. Sieve tubes conduct organic food. **Phloem parenchyma** cells store food and help in the lateral conduction of food. Companion cells are supposed to control the function of sieve tubes.

On the outer side of the vascular tissues of a bundle may be found a few layers of **sclerenchyma fibres**. They are, however, more abundant on the upper region just above the xylem. They provide rigidity and mechanical strength to the leaf.

5. **Midrib.** Mesophyll is absent in the region of midrib and other larger veins. Collenchyma or sclerenchyma occurs towards the two epidermal layers for providing mechanical strength. The centre contains a number of vascular bundles which are embedded in a parenchymatous ground tissue.

Isobilateral Leaf (Typical Monocot Leaf, Fig. 6.36)

The isobilateral monocot leaves usually do not show a distinction into petiole and lamina. The leaf base is commonly sheathing, that is, covering the stem partially or completely. The venation is parallel. Both the surfaces can face the sun. Therefore, the two surfaces are equally green (Gk. *iso*— equal, *bi*— two, *lateris*— side). The internal structure also does not show much differentiation of upper and lower sides. The various parts of a typical isobilateral leaf (*e.g.*, Maize) are as follows:

1. **Epidermis.** A uniseriate or single-layered epidermis occurs on the two sides of the leaf. The epidermis consists of compactly arranged oval rectangular transparent parenchymatous cells. The cells are thickened on the free side where silica and cutin are deposited. A distinct layer of cuticle occurs on the outside.

At places the upper or adaxial epidermis contains groups of larger thin-walled protruding and turgid cells over the region of veins. They are called **bulliform** or **motor cells.** The cells are highly vacuolate and can store water, if available. However, in case of water deficiency the bulliform cells lose water and become flaccid. As a result the leaf gets rolled up to reduce the exposed surface. The bulliform cells are also useful in the unrolling of leaf during its development.

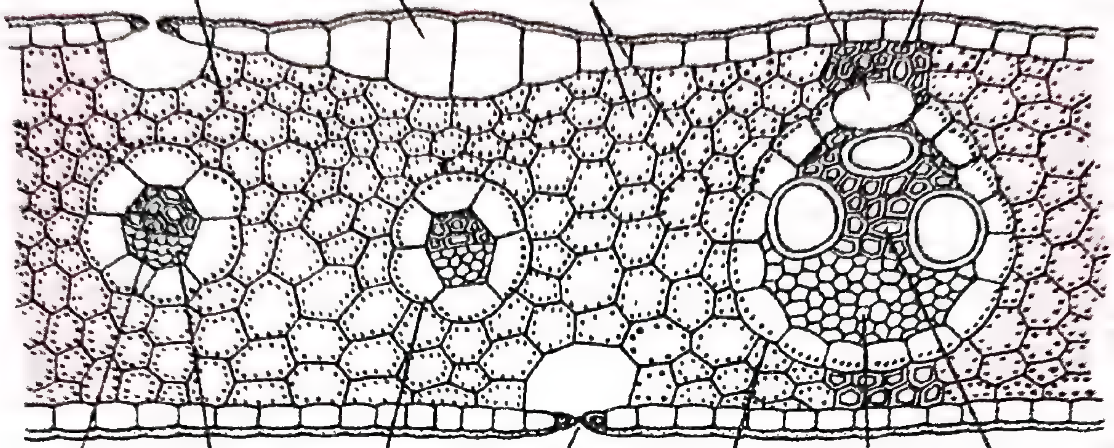


Fig. 6.36. V.S. or T.S. portion of Maize (or Monocot) Leaf.

Both the surfaces contain **stomata**. The leaf is, therefore, **amphistomatic.** Each stoma or stomate is lined by a pair of dumb bell-shaped **guard cells.** Unlike other epidermal cells, guard cells contain a few chloroplasts. The guard cells are further associated with a pair of specialized epidermal cells called **subsidiary cells** or **accessory cells**. Due to their peculiar thickening the guard cells can create a pore in between them when they get swollen due to endosmosis. Each stomate or stoma leads internally into an air space called **substomatal cavity** or **chamber.**

The various functions of the epidermis are (i) protection of internal tissues (ii) protection from microbial attack due to cuticle and silica (iii) gaseous exchange through stomata (iv) allowing transpiration through stomata (v) reduction in the rate of transpiration through epidermal cells due to the presence of cuticle (vi) folding of leaves during drought with the help of bulliform or motor cells (vii) unfolding of the young leaves by means of motor or bulliform cells.

2. **Mesophyll.** It lies in between the two layers of epidermis. Mesophyll is not differentiated into palisade and spongy tissues. Instead, the undifferentiated mesophyll is similar to spongy tissue. It consists of large isodiametric cells which appear oval or rounded in a transverse section. The mesophyll cells enclose intercellular spaces which are, however, smaller than those of the typical spongy parenchyma. The intercellular spaces form an aerating system which communicates with the stomata through substomatal cavities.

The mesophyll cells are chlorenchymatous and contain a number of chloroplasts. Therefore, mesophyll constitutes the photosynthetic tissue of the leaf.

Differences between Dicot (Dorsiventral) and Monocot (Isobilateral) Leaves

Dicot (Dorsiventral) Leaf	*Monocot (Isobilateral) Leaf*
1. The upper surface is dark green while the lower surface is light green.	1. The two surfaces are equally green.
2. The epidermal cells have sinuous lateral walls.	2. The epidermal cells have almost straight lateral walls.
3. Silica is not normally deposited on the epidermal cells.	3. Silica deposition occurs on the walls of epidermal cells.
4. Stomata are absent or less abundant on the upper side.	4. The stomata are equally distributed on the two sides.
5. The stomata have kidney-shaped guard cells.	5. The stomata have dumb bell-shaped guard cells.
6. The veins do not run parallel. Instead they form reticulations.	6. The veins run parallel to one another.
7. Mesophyll is differentiated into two parts, upper palisade and lower spongy.	7. Mesophyll is undifferentiated.
8. Protoxylem is indistinguishable.	8. Larger vascular bundles may show distinction into protoxylem and metaxylem.
9. Bundle sheath is generally single layered and formed of colourless cells.	9. Bundle sheath may be single or double layered. The cells generally possess chloroplasts.
10. Bundle sheath extensions are parenchymatous.	10. Bundle sheath extensions are sclerenchymatous.
11. Hypodermis of the midrib region is collenchymatous.	11. Hypodermis of the midrib region is sclerenchymatous.

3. **Vascular System**. A large number of closely placed small and a few large vascular bundles run parallel to one another in the mesophyll. Each vascular bundle is surrounded by a single sheath of compactly arranged parenchyma cells called **border parenchyma** or **bundle sheath**. It is chlorenchymatous. The cereals with a single bundle sheath are called **panicoid** grasses. Double bundle sheath occurs in *Triticum* (Wheat) and some other cereals. They are called **festucoid grasses**. Larger vascular bundles bear **bundle sheath extensions**. The extensions are sclerenchymatous and provide mechanical strength to the leaf.

The vascular bundles are conjoint, collateral and closed. Phloem lies towards the lower side while xylem is found towards the upper side. Phloem consists of sieve tubes and companion cells. Xylem is formed of vessels, tracheids and xylem parenchyma. In small vascular bundles the xylem is compact. In larger vascular bundles xylem is similar to that of stem— with two large, pitted, oval and lateral metaxylem vessels connected by tracheids and smaller spiral or annular oval protoxylem vessels towards the upper side where a **protoxylem lacuna** or **cavity** is also present. Protoxylem being present on the upper or inner side, xylem is endarch.

In Maize leaf the undifferentiated mesophyll occurs in concentric layers around vascular bundles having large centrifugal chloroplasts in its large bundle sheath cells. Such an arrangement is called **Kranz anatomy**.

4. **Midrib**. It is the thickest part of the leaf. Midrib is represented by a shallow groove on the upper surface and a broad ridge on the lower surface. The wide midrib does not contain any mesophyll. Sclerenchyma occurs in patches inner to both the upper and lower epidermis. A number of parallel running vascular bundles are embedded partially in the

sclerenchyma found towards the lower side. The remaining ground tissue is made up of nongreen parenchyma.

Other Leaf Types

Multilayered epidermis is found in a few leaves like *Ficus, Begonia* and *Nerium*. In xerophytic leaves, spongy parenchyma is reduced. Palisade parenchyma may occur on both upper and lower sides with spongy parenchyma sandwitched between the two, *e.g., Nerium*. In *Nerium* or Oleander, the lower surface bears deep depressions called **crypts** (stomatal crypts). The crypts possess a number of cutinised hair and stomata. In other xerophytic plants, stomata occur individually and are **sunken** below the surface due to their being overtopped by accessory or subsidiary cells.

Floating leaves possess stomata on the upper surface (epistomatic) only, *e.g., Nymphea*. Submerged hydrophytic leaves do not have stomata (*e.g., Hydrilla, Potamogeton*). The leaves are covered by mucilage. Internally, they have thin undifferentiated mesophyll. Mechanical tissue is absent. Aerenchyma is present. Xylem is reduced. It may be replaced by a cavity.

ADDITIONAL INFORMATION

- **N. Grew** (1682). Father of Plant Anatomy. Gave the terms of tissue and parenchyma.
- **Nageli** (1858). Gave the terms of meristem, xylem and phloem.
- **Hartig** (1837). Discovered sieve tubes.
- **Schleiden** (1839). Discovered and gave the term collenchyma.
- **Angiosperms without Vessels**. Families Winteraceae, Tetracentraceae and Trocho-dendraceae. Wood without vessels is **homoxylous** while the one with vessels is **heteroxylous**.
- **Gymnosperms with Vessels**. Members of group gnetales.
- **Pteridophytes with Vessels**. Occasional in species of *Selaginella, Dryopteris, Marsilea*, etc.
- **Endodermoid**. The term is used by some authors for endodermis or starch sheath of young stems because of the absence of casparian strips.
- **Leaf Primordium**. Develops from a lateral protrusion or leaf buttress. It grows initially by an apical meristem (permanent in ferns) and then by intercalary meristem.
- Leaf consists of only primary tissues. Secondary growth is limited to wound healing.
- **Cavities**. Of three types: (i) **Schizogenous**. By enlargement of intercellular spaces or separation of cells, *e.g.*, oil duct of Sunflower. (ii) **Lysigenous**. By degeneration of cells, *e.g.* oil cavity of *Citrus*. (iii) **Schizolysigenous**. Partly by separation and partly by degeneration of cells, *e.g.*, protoxylem cavity in Maize stem (Protoxylem or water cavity of Maize stem was formely called lysigenous cavity).
- **Knot**. Wound or base of a fallen branch covered by growth of secondary tissues around it.
- **Abscission**. It involves formation of a

special parenchymatous layer called **abscission** or **separation** layer at the base of organ and a layer of suberised thick-walled 'cork' cells called **protective layer** over the mother axis. Degeneration of cells of abscission or separation layer causes abscission.

- **Heartwood.** Most abundant in Mulberry but absent in Poplar and Willow.
- **Most Durable Soft Wood.** *Cedrus deodara.*
- **Most Durable Wood.** Teak (*Tectona grandis*).
- **Lightest Wood.** *Ochroma pyramidale* (= *O. lagopus*).
- **Heaviest Wood.** *Gualacum officinale.* In India *Acacia sundra..*

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. State the location and functions of different types of meristems.

✓ On the basis of location, meristems are of three types — apical, intercalary and lateral.

(i) **Apical.** It is present at the apices of stem, root and their branches.
Functionas. (i) Growth in length (ii) Formation of primary tissues.

(ii) **Intercalary.** It is found above or below stem nodes and leaf bases.
Functions. (i) Growth of internodes. (ii) Growth in leaves. (iii) Correction of position in lodged stems.

(iii) **Lateral.** (a) **Phellogen** (Cork cambium). It develops from hypodermis in stems and pericycle in roots. **Function.** Formation of protective cork (phellem) and aerating lenticles on the outside and secondary cortex (phelloderm) on the inner side. (b) **Vascular Cambium.** In stem from intra- fascicular cambial strips and interfascicular strips. In root from conjuctive parenchyma and pericycle. **Function.** Formation of secondary phloem on outside and secondary xylem on inner side. Vascular rays are formed at intervals for radial conduction.

2. Cork cambium forms tissues that form the cork. Do you agree with this statement. Explain.

✓ **Yes.** Cork combium or **phellogen** is a secondary meristem that develops from pericycle of root and hypodermal layer of stem. Its cells show bipolar divisions, *i.e.,* divisions both on the outerside and inner side. The tissue formed on the outer side is initially living and parenchymatous. Soon its walls become suberised. Living protoplasm dies. The empty cells get filled with tannins, alkaloids and air. The dead suberised tissue is called **cork** or **phellen**.

3. Explain the process of secondary growth in stems of wood angiosperms with the help of schematic diagrams. What is its significance ?

✓ Secondary growth of a woody angiosperm stem occurs by two types of cambia, vascular cambium and cork cambium.

Vascular Cambium. It is formed partly by primary intrafassicular cambial strips and partly by secondary interfascicular strips from medullary rays. Cells of vascular cambium divide both on the outerside as well as on the inner side. Vascular cambial cells called **fusiform initials** form **secondary pholem** on the outer side and **secondary xylem** on the inner side. At places vascular cambium possesses **ray initials**. They form **vascular rays** (or secondary medullary rays), **pholem rays** in secondary pholem and **wood rays** in secondary xylem.

Secondary pholem or **bast** forms a narrow circle on the outside. As new secondary pholem becomes functional, the previous older pholem gets crushed. Secondary xylem or wood persists. As a result wood grows with age. In order to accomodate it the vascular cambium also grows in diameter by addition of new cells. The phenomenon is called **dilation**.

The yearly growth of wood is distinct in temperate areas. It is called **annual ring**. In each annual ring there is wide **spring** or **early wood** of broader light coloured elements and a narrow **autumn** or **late wood** of narrow dark coloured elements. In old stem, the central part of wood becomes nonfunctional and dark coloured due to tyloses and deposit of resins, gums, tannins. It is called **duromen** or **heart wood**. The outer functional wood is called **sapwood** or **alburnum**.

Cork cambium (Phellogen). It produces secondary growth tissues collectively called **periderm.** Cork cambium develops secondarily from a subepidermal layer of living cells. It produces **phellem** or **cork** on the outside and secondary cortex or **phelloderm** on the inner side. Cork consists of dead, suberised and impermeable cells. At places aerating pores called **lenticels** occur. A lenticel

has loosely arranged suberised **complementary cells**. The interspaces help in gaseous exchange. (Refer to Fig. No. 6.29 A, C and D)

Significance of Secondary Growth. Refer to the text.

4. Draw illustrations to bring out anatomical differences between (a) Monocot root and dicot root (b) Monocot stem and dicot stem.

✓ (a) Draw Fig. 6.22 and Fig. 6.23 and **mark**. (i) Wider cortex in monocot root, (ii) Larger number of vascular bundles in monocot root (iii) Presence of pith in monocot root (iv) Rounded vessels in monocot root and polygonal in dicot root.

(b) Draw Fig. 6.27 B and 6.28 B and **mark**. (i) Presence of multicellular hair in dicot and their absence in monocot stem. (ii) Occurrence of collenchymatous hypodermis in dicot stem and sclerenchymatous hypodermis in monocot stem. (iii) Differentiation of cortex, endodermis, pericycle and pith in dicot stem and undifferentiated ground tissue in monocot stem. (iv) Vascular bundles in a ring in dicot stem and scattered in monocot stem. (v) Vascular bundles are open in dicot stem and closed in monocot stem. (vi) A sclerenchymatous sheath and an internal cavity (protoxylem or schizolysigenous cavity) present in vascular bundles of monocots but absent in dicots. (vii) Vessels are polygonal in dicot stem and rounded in monocot stem.

5. Cut a transverse section of young stem of a plant from your school garden and observe it under the microscope. How would you ascertain whether it is monocot stem or dicot stem ? Give reasons.

✓ The section is of dicot stem if it has concentric arrangement of ground tissues, open vascular bundles arranged in a ring and polygonal vessels. It is of monocot stem if the ground tissue is undifferentiated, vascular bundles are closed and scattered, each with a sclerenchymatous sheath, protoxylem cavity and rounded vessels.

7. Why are xylem and pholem called complex tissues ?

✓ A complex tissue is the one which contains two or more than two types of cells which have a common origin and coordinate to perform a common function. Both xylem and pholem are complex tissues. **Xylem** is formed of four types of cells – tracheids, vessles, xylem parenchyma and xylem fibres. All of them coordinate to help in conduction of sap.

Pholem is formed by four types of cells – sieve tubes, companion cells, pholem parenchyma and pholem fibres. They coordinate to conduct food.

8. What is stomatal apparatus ? Explain the structure of stomata with a labelled diagram.

✓ Stomatal apparatus is a pair of guard cells with or without surrounding subsidiary cells which function as a value to open or close a stomatal pore for gaseous exchange and transpiration.

The gurad cells are reniform in most of the plants. They are dumb-bell-shaped in grasses. The guard cells contain chloroplasts and small vacuoles. They are thick-walled in the area of contact and thin-walled elsewhere. As the gurad cells swell up due to endosmosis their thin-walled sides expand. The thick walls of the two gurad cells also bend outwardly and create a pore in between them. Fig 6.16.

9. Name the three basic tissue systems in the flowering plants. Give the tissue names under each system.

✓ The three basic tissue systems are epidermal, ground and vascular.

Epidermal Tissue System. Epidermis and epidermal appendages. Epidermis consists of epidermal cells and guard cells. Epidermal appendages include root hairs, stem hairs, stinging hairs, glandular hairs and emergences.

Ground Tissue System. Hypodermis, cortex, endodermis, pericycle, pith and medullary rays.

Vascular Tissue System. Vascular bundles. They can have pholem, xylem and vascular cambium.

10. What is periderm ? How does periderm formation takes place in the dicot stem ?

✓ **Periderm** is a component of secondary growth that is formed towards the surface of stems and roots, having phellem, phellogen and phelloderm.

Phellogen or **Cork cambium** develops in a subepidermal layer in stem and from pericycle in roots, Its cells undergo bipolar divisions. The cells formed on the outer side undergo suberisation, deposition of tannins and death of cellular contents. The outer tissue of dead suberised cells is called **cork** or **phellem**. At places it conains **lenticels** or aerating pores having loosely arranged suberised complementary cells.

Cells formed by phellogen on the inner side constitute secondary cortex or phelloderm.

11. How is the study of plant anatomy useful to us ?

✓ Refer to the text.

12. Describe the internal structure of a dorsiventral leaf with the help of labelled diagrams.

✓ Refer to the text. Fig. 6.36.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Which industry depends on the knowledge of wood anatomy ?
   ✓ Plywood industry
2. Which meristem does produce growth in length ?
   ✓ Primary meristem.
3. What is conjunctive tissue ?
   ✓ It is a narrow strip of tissue (parenchymatous or sclerenchymatous) that lies between xylem and phloem bundles of root.
4. Name the most durable wood ?
   ✓ Teak (*Tectona grandis*).
5. What forms the cambial ring in a dicot stem during the secondary growth ?
   ✓ Fascicular and interfascicular strips of meristem.
6. When do you refer to a vascular bundle as a closed bundle ?
   ✓ The vascular bundles that lack cambium are called closed bundles, *e.g.*, in monocot stems.
7. From where does the lateral root originate ?
   ✓ Pericycle of mature zone.
8. What makes the apical meristem of the root sub-terminal ?
   ✓ Presence of protective root cap.

One Mark Questions (Without Answers)

1. Give suitable terms for : (i) Strip of annual wood formed during period favourable for growth of the plant (ii) Upper surface of the leaf.
2. There are two unlabelled microscopic slides showing transverse sections of root and stem of a dicot plant. How will you differentiate between the two on the basis of the arrangement of the conducting tissue ?
3. Name two types of sieve elements found in phloem.
4. Name the anatomical layer in the root from which the lateral branch of root arises.
5. What is palisade parenchyma ?
6. Name the components of secondary xylem.
7. Define bicollateral vascular bundle.
8. Define collateral vascular bundle.
9. Differentiate fusiform initials and ray initials.
10. Which tissue of the leaf contains chloroplasts ?
11. Define meristems.
12. Why is cambium considered to be a lateral meristem ?
13. Name the type of plant tissue that has characteristically thin-walled cells and retains the capacity of division even at maturity.
14. What is an annual ring ?
15. Name the tissue represented by the jute fibres used for making the ropes.

Two Mark Questions (Without Answers)

1. Distinguish between (a) Tracheid and vessel (b) Sieve cell and sieve tube member (c) Phellem and phelloderm (d) Fascicular cambium and interfascicular cambium (e) Softwood and hardwood.
2. Cork cambium forms tissues that form the cork. Do you agree with this statement ? Explain.
3. Cut a transverse section of young stem of a plant from your school garden and abserve it under the microscope. How would you ascertain whether it is monocot stem or dicot stem. Give reasons.
4. What is the difference between fibres and sclereids in plant histology. Give one example of each.
5. What are the general characteristics of sclerenchyma tissue ? Which type of cells of this tissue are the cause of grittiness of the pulp of pear ?
6. Name the main components of xylem. Which of these is suitable for carrying water ?
7. What are medullary rays and what are their functions ?
8. How open vascular bundles differ from closed vascular bundles ?

9. Distinguish between vessels and sieve tubes.
10. Give any four differences between tracheids and vessels.

Three Mark Questions (Short Answer Type)

1. Why a large number of stomata are present at the lower surface of the dicotyledonous leaves in the terrestrial plants?
2. Mention two differences in the vascular bundles of sunflower and maize stems.
3. What are the differences between the root hairs and stem hairs?
4. Where are the companion cells located in flowering plants ? What is their function ?
5. Name the main components of xylem. Which of these is most suitable for carrying water ?
6. Differentiate between Root apex and shoot apex.
7. Answer the following with reference to the anatomy of dicot root. (i) Where is pericycle located ? (ii) How are the xylem vessels arranged ? (iii) What do you call such an arrangement ? Which type of cells constitute the cortex ?
8. A T.S. of a trunk of a tree shows concentric rings which are known as growth rings. How are these rings formed ?
9. Give at least two functions of the following : (a) Parenchyma (b) Periderm.
10. What is collenchyma? Explain its structure and function in plant body of a herbaceous angiosperm?

Five Mark Questions (Long Answer Type)

1. Describe the structure and organisation of stem apex.
2. Write a note on parenchyma.
3. Sketch the elements of (a) Xylem and (b) Phloem.
4. Name and define the different types of vascular bundles.
5. Briefly describe the anatomy of primary dicot root.
6. Discuss the internal structure of monocot roots.
7. With the help of diagrams, depict secondary growth in dicot roots.
8. What is xylem ? Explain the structure of various kinds of components of xylem.
9. (a) Differentiate between structure of vascular bundle of a dicot stem and a monocot root.
(b) Draw a labelled diagram of vascular bundle of a monocot stem.
10. Draw a labelled diagram of T.S. of dicot root. Give four differences between internal structure of dicot and monocot root.
11. Draw a well labelled diagram of a typical dicot stem.

Multiple Choice Questions

(1) Lacunate collenchyma occurs in stem of (a) *Leucas* (b) *Cucurbita* (c) Sunflower (d) *Sambucus*. *(JKCET 2007)*

(2) Thin-walled passage cells occur in (a) pholem elements as entry points (b) testa for emergence of embryonal axis (c) central area of style for passage of pollen tube (d) endodermis of root for quick transport of water from cortex to pericycle. *(CBSE 2007)*

(3) In angiosperms, vascular tissues develop from (a) Phellogen (b) Dermatogen (c) Plerome (d) Periblem. *(CBSE 2008)*

(4) In sugarcane, length of internodes is variable due to (a) intercalary meristem (b) shoot apical meristem (c) size of lamina of lower node (d) position of axillary buds. *(CBSE 2008)*

(5) Annular and spirally thickened conducting elements generally develop in protoxylem when root or stem is (a) widening (b) differentiating (c) maturing (d) elongating. *(CBSE 2009)*

(6) In Barley stem, vascular bundles are (a) open and scattered (b) closed ad scattered (c) closed and radial (d) open and in a ring. *(CBSE 2009)*

(7) Quiescent centre is found in plant at (a) root tip (b) shoot tip (c) cambium (d) leaf tip. *(WB 2010)*

(8) Closed vascular bundles are the ones which (a) contain cambium (b) lack cambium (c) lack xylem (d) possess lysigenous cavity. *(AFMC 2010)*

(9) An old trunk of *Dalbergia* tree would have maximum amount of (a) Primary phloem (b) primary xylem (c) secondary xylem (d) secondary cortex. *(RPMT 2011)*

(10) Ground tissue consists of (a) Epidermis and cortex (b) All tissues internal to endodermis (c) All tissues external to endodermis (d) All tissues except epidermis and vascular tissues. *(AMU 2011)*

(11) Common bottle cork is product of (a) Xylem (b) Dermatogen (c) Phellogen (d) Vascular cambium. *(CBSE 2012)*

(12) Water containing cavities in vascular bundles occur in (a) Sunflower (b) Maize (c) *Pinus* (d) *Cycas*. *(CBSE 2012)*

(13) Centrifugal development of xylem occurs in (a) Root (b) Leaf (c) Flower (d) Stem. *(MP PMT 2013)*

(14) Arrangement of vascular bundles in a dicot root is (a) collateral (b) Radial (c) Bicollateral (d) Conjoint. *(JKCET 2013)*

(15) Lenticels are involved in (a) Photosynthesis (b) Transpiration (c) Gaseous exchange (d) Food transport. *(NEET 2013)*

(16) Tracheids differ from other tracheary elements in (a) being imperforate (b) lacking nucleus (c) being lignified (d) having casparian strips. *(CBSE 2014)*

(17) Increase in length of petiole results from division of
(a) apical meristem (b) lateral meristem (c) intercalary meristem (d) phellogen. *(AMU 2015)*

(18) No vessels are found in the wood of (a) Pine (b) Eucalyptus (c) Teak (d) Sheesham. *(AMU 2015)*

(19) The baloon-shaped structures called tyloses (a) are linked to ascent of sap through xylem vessels (b) originate in the lumen of vessels (c) characterise the sapwood (d) are extensions of xylem parenchyma cells into vessels. *(NEET 2016)*

(20) Which of the following is made up of dead cells (a) Xylem parenchyma (b) Collenchyma (c) Phellem (d) Phloem. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the A and R statements, mark the correct answer as

(a) If both A and R are true and R is correct explanation of A

(b) If both A and R are true and R is not correct explanation of A

(c) If A is true and R is false (d) If A and R are false.

1. **Assertion.** In collateral bundles, pholem is situated towards inner side.
Reason. In monocot stem, cambium is present. *(AIIMS 2008)*
A B C D

2. **Assertion.** In angiosperms, transport of food and water is more efficient than gymnosperms and pteridophytes.
Reason. In angiosperms longitudinally arranged sieve elements and vessels with perforated end walls are present. *(AIIMS 2011)*
A B C D

3. **Assertion.** No secondary growth takes place in monocots.
Reason. Secondary growth is not related to with cambium. *(AIIMS 2015)*
A B C D

ANSWERS

Multiple Choice Questions

(1) —b (2) —d (3) —c (4) —a (5) —d (6) —b (7) —a (8) —b (9) —c (10) —d
(11) —c (12) —b (13) —d (14) —b (15) —c (16) —a (17) —c (18) —a (19) —c (20) —c

Assertion and Reason Type Questions

(1) —D (2) —A (3) —B

Chapter

7 Structural Organisation in Animals — Animal Tissues

THEORY–a quick rundown

A **tissue** is a group of cells that are similar in structure, origin and function. The term 'tissue' was given by **Bichat**. The branch of science dealing with the tissues is called **'histology'. Mayer** introduced the term histology. **Malpighi** is considered the **"founder of histology".**

Broadly animal tissues are classified into four types : epithelial, connective, muscular and neural.

I. EPITHELIAL TISSUE

Origin. Epithelial tissue evolved first and are also formed first in the embryo. This tissue arises from all the three primary germ layers : **ectoderm, mesoderm** and **endoderm**, of the embryo.

Basement membrane consists of secretions of epithelial cells and a layer of underlying connective tissue.

Usually blood vessels are absent in epithelial tissue. The epithelial tissue has a *good power of repair* (*regeneration*) after injury.

A specialized epithelium, the **stria vascularis** of the cochlea of internal ear has blood capillaries within the thickness of the epithelium.

Types of Epithelial Tissue. On the basis of arrangement and shape of the cells, it is two types: simple and compound.

(A) Simple Epithelia (Unilayered Epithelia)

1. **Squamous epithelium** (Pavement epithelium). This epithelium is present in the terminal bronchioles and alveoli of the lungs, wall of the Bowman's capsules and parts of loops of Henle of the nephrons of the kidneys, membranous labyrinth (internal ear), blood vessels, lymph vessels, heart, coelomic cavities, and rete testis of the testis. In the blood vessels, lymph vesels and heart it is called **endothelium**. In the coelom, it is called **mesothelium**. The cells of endothelium and mesothelium become wavy, hence these epithelia are called **'tessellated'**.

2. **Cuboidal epithelium.** The cubical epithelium is present in the small salivary and pancreatic ducts, thyroid vesicles, parts of membranous labyrinth, nephrons of kidneys, ovaries, seminiferous tubules of testes, and ciliary bodies, choroid and iris of eyes and in Bartholin ducts.

3. **Columnar epithelium**. It is present in the stomach and intestine. It is also present in the gall bladder and bile duct. It also occurs in the gastric glands, intestinal glands and pancreatic lobules where it has secretory role and is called **glandular epithelium**.

4. **Ciliated epithelium**. The ciliated epithelium is of two types. (i) **Ciliated columnar epithelium**. This epithelium lines most of the respiratory tract and fallopian tubes (oviducts). It also lines the ventricles of the brain and the central canal of the spinal cord. It is also present in tympanic cavity and auditory tube (eustachian tube). (ii) **Ciliated cuboidal epithelium**. It occurs in certain parts of nephrons of the kidneys.

5. **Pseudostratified Epithelium**. It is of two types : (i) **Pseudostratified columnar epithelium**. It occurs in the large ducts of certain glands such as parotid salivary glands and the urethra of the human male. (ii) **Pseudostratified columnar ciliated epithelium**. This epithelium occurs in the trachea and large bronchi. The movements of the cilia propel the mucus and foreign particles towards the larynx.

Some of the columnar or cuboidal cells form **glandular epithelium**. They are mainly of two types : unicellular, consisting of isolated glandular cells, *e.g.*, goblet cells of the alimentary canal and multicellular consisting of group of cells, *e.g.*, salivary glands.

(B) Compound Epithelium (Multilayered Epithelium)

1. **Stratified Epithelium**. It is of four types :

(i) **Stratified squamous epithelium**. It is of two types : (a) **Keratinised stratified squamous epithelium**. This epithelium occurs in the epidermis of the skin of land vertebrates. (b) **Non-keratinised stratified squamous epithelium**. This epithelium occurs in the oral cavity (buccal cavity), pharynx, oesophagus, anal canal, lower parts of urethra, vocal cords, vagina, cervix (lower part of uterus) and cornea and conjunctiva of eye. (ii) **Stratified cubical epithelium**. It lines the inner surface of salivary and pancreatic ducts. (iii) **Stratified columnar epithelium**. It covers the epiglottis and parts of urethra. (iv) **Stratified columnar ciliated epithelium**. It is present in the larynx and uper part of the soft palate.

2. **Transitional Epithelium (Urothelium)**. The transitional epithelium is found in the wall of urinary bladder, ureter, renal pelvis and upper part of urethra.

Olfactory mucosa (present in the nasal chamber) is also called **Schneiderian membrane**. The olfactory receptors are modified neurons.

Specialized Junctions between Epithelial Cells

(i) **Tight Junctions (= Zonula occludens)**. Plasma membranes in the apical parts of the adjacent epithelial cells become tightly packed together or are even fused to form the tight junctions. They check the flow of materials between the cells.

(ii) **Gap Junctions**. Gap junctions do not provide physical support but are meant for chemical exchange between adjacent cells.

(iii) **Adhering Junctions**. They perform cementing function to keep neighbouring cells together.

Adhering Junctions are of three Types : Zonula adherens, Desmosomes (Macula adherens) and hemidesmosomes.

- According to the site where secretion is released, the glands are of two types: exocrine and endocrine.

(a) Exocrine Glands. The glands which pour their secretions on the epithelial surface, directly or through ducts are called **exocrine glands** (= externally secreting glands). These include salivary glands, gastric glands, intestinal glands, tear glands, sweat glands, oil glands, mammary glands, etc.

The exocrine glands may be **unicellular** or **multicellular.**

(b) Endocrine Glands (= Ductless Glands). Their secretions are called **hormones** which are poured directly into the blood and lymph which carry hormones to the target organs. Examples of endocrine glands are thyroid, parathyroids, hypothalamus, pituitary, adrenals, thymus, etc.

On the basis of *mode of secretion*, the glands are of three types : merocrine, apocrine and holocrene.

(i) **Merocrine glands.** Only secretion is discharged by the cells. There is no loss of cells or their parts, *e.g.*, goblet cells, most sweat glands, salivary glands and intestinal glands.

(ii) **Apocrine glands.** The apical part break off from the cells and discharged as secretion, *e.g.*, mammary glands and some sweat glands.

(iii) **Holocrine glands.** Entire cells are discharged as parts of secretion, *e.g.*, Sebaceous glands. Sometimes, holocrine glands are described as those endocrine glands which secrete only hormones, *e.g.*, thyroid, parathyroids, adrenals, pituitary and hypothalamus.

Zymogen granules appear in the cytoplasm of the secretory cell.

II. CONNECTIVE TISSUE

Origin. Connective tissue is formed by the **mesoderm** of the embryo.

General Structure. Three components are present in the connective tissues. These are intercellular medium, connective tissue cells and fibres.

(i) **Intercellular Medium** (ground substance). It is mainly a mixture of carbohydrates and proteins. These have been identified as various forms of mucopolysaccharides. The most common mucopolysaccharide ground substance is **hyaluronic acid.**

(ii) **Connective Tissue cells.** The cells are of different types (a) **Fibroblasts** produce fibres and matrix. (b) **Adipose cells** (= Adipocytes or Lipocytes) store fat. (c) **Plasma cells** (= Plasmatocytes) synthesize antibodies. Plasma cells are also called **'Cart Wheel Cells'** because thin chromatin in the nucleus forms four or five clumps giving the nucleus a resemblance to a cart wheel. (d) **Mast cells** (= Mastocytes) produce histamine, heparin and serotonin. Mast cells are related to **basophils** of the blood. **Histamine** dilates the walls of blood vessels in inflammatory and allergic reactions while **heparin** checks clotting of blood inside the blood vessels. **Serotonin** acts as a vasoconstrictor to arrest bleeding and to increase blood pressure. (e) **Macrophages** (= Histocytes or Clasmatocytes) ingest cell debris, bacteria and foreign matter. Macrophages are derived from monocytes. (f) **Lymphocytes** ingest cell debris, bacteria and foreign matter. (g) **Mesenchyme cells** give rise to various types of connective tissue cells. (h) **Chromatophores** (Pigment cells) are found in the dermis of the skin where they impart colour to the animal. (i) **Reticular cells.** They form reticular tissue and are phagocytic in nature.

- **Monocytes, eosinophils** and **neutrophils** may be present in the connective tissue. Lymphocytes, monocytes, eosinophils, basophils and neutrophils are WBCs and are described in detail in the blood.

(iii) **Connective Tissue Fibres.** (a) **Collagenous or collagen fibres** (white fibres) are made up of **collagen** protein. When boiled in water collagen changes into gelatin. These fibres occur in bundles and are unbranched and inelastic. (b) **Elastic fibres** (yellow fibres) are formed of a protein called **elastin.** These fibres are branched and elastic. (c) **Reticular fibres.** These fibres are delicate, branched and inelastic. They are made up of **reticulin** protein. They always form a net work.

Types of Connective Tissue. The connective tissue can be divided into the following three main groups : loose connective tissue, dense connective tissue and specialised connective tissue.

1. **Loose Connective Tissue.** It is are of two types : areolar tissue and adipose tissue

(i) **Areolar Tissue.** It forms a continuous thin sheet between the skin and muscles. It also attaches the blood vessels and nerves with surrounding tissues.

(ii) **Adipose Tissue.** The tissues are found in the subcutaneous tissue, around the heart, kidneys, eyeballs, mesenteries and omenta, where fat is stored. It is also found in the **blubber** of whales and elephants, **hump** of camel, **fat bodies** of frog and yellow bone marrow.

2. **Dense Connective Tissue.** It is of two types : dense regular connective tissue and dense irregular connective tissue.

(i) **Dense Regular Connective Tissue.** It is further of two types :

(a) **White fibrous connective tissue.** It has two forms : (i) **Cords.** The white fibres form cords called **tendons** which connect the muscles with the bones. (ii) **Sheets.** They occur in the pericardium of the heart, duramater of the brain and spinal cord, capsule of the kidney, perichondrium of cartilage, periosteum of bone, sclera and cornea of eye ball.

(b) **Yellow elastic connective tissue.** It also has two forms : (i) **Cords.** They are formed by yellow elastic tissue and are called **ligaments** which join bones together. (ii) **Sheets.** These are also formed by yellow elastic tissue and occur in the walls of blood vessels, lungs and bronchioles.

(ii) **Dense irregular connective tissue.** It is present in the skin.

3. **Specialised Connective Tissues.** These are of the following types :

Skeletal Tissues. These are of two types : Cartilage and bone.

(a) **Cartilage.** The cartilages are of three types : (i) **Hyaline cartilage.** It forms articular surfaces at the joints of long bones, where it is called articular cartilage. It also forms part of larynx and sternum, rings of trachea and bronchi, sternal parts of ribs, hyoid apparatus and nasal cartilage. (ii) **Fibrous cartilage.** It is of two types : (a) **White fibrous cartilage** occurs in the inter-vertebral discs where it acts as cushion and in the pubic symphysis where it helps in parturition (process of birth). (b) **Yellow Elastic cartilage** is found in the pinna and external auditory canal of the ear, Eustachian tubes, epiglottis and tip of the nose. It makes these organs flexible. (iii) **Calcified cartilage.** Sometimes matrix contains granules of calcium carbonate, then the cartilage is called calcified cartilage; found in suprascapula of pectoral girdle of frog and vertebrae of shark.

(b) **Bone.** The mammalian bones consist of the following parts : (i) **Periosteum.** Comprises two distinct layers; a thin outer layer of fibrous connective tissue and a layer of **osteoblasts.** The latter are called bone forming cells. (ii) **Matrix.** Composed of a protein called **ossein.** It forms thin plates called **lamellae.** The lamellae which occur around the **Haversian canals** (a characteristic of mammalian bones) are termed the **Haversian lamellae.** Some lamellae are present around the bone marrow cavity called circumferential lamellae. In the lamellae minute bone cells, the **osteocytes** are present. An osteocyte is surrounded by a space called **lacuna.** The lacunae lead into fine channels the **canaliculi** (minute canals) containing **protoplasmic processes** of the osteocytes. With the help of canaliculi, one osteocyte is in contact with another osteocyte. A Haversian canal and its lamellae and osteocytes form a **Haversian system.** The lamellae between the Haversian systems are called **interstitial lamellae.** The Haversian canals are interconnected by transverse channels termed the **Volkmann's canals.** (iii) **Endosteum.** Comprises two distinct layers; a thin inner layer of fibrous connective tissue and a layer of osteoblasts which produce new bone material. (iv) **Bone marrow.** The bone marrow cavity is filled with a soft and semisolid fatty neurovascular tissue termed as **bone marrow.**

Types of Bone Marrow. (a) **Red bone marrow.** Present in the epiphyses and produces red blood corpuscles, white blood corpuscles (monocytes ; eosinophils, basophils and neutrophils) and

platelets. (b) **Yellow bone marrow**. It is yellow in colour and contains much fatty tissue; produces blood corpuscles in emergency. Yellow bone marrow may be replaced by red bone marrow in anaemia.

A mature bone generally has two types of parts (tissues) spongy and compact : (i) **Spongy or cancellous part of bone**. It is found at the ends of long bones (epiphyses). Spongy bone contains red bone marrow and is without Haversian system. It is found in the vertebrae, ribs and skull bones. (ii) **Compact or dense part of bone**. It is comparatively hard and compact; found in the shaft of long bones. It contains yellow bone marrow and has Haversian system.

Bone acts as a homeostatic reservoir for ions like calcium, magnesium and phosphorus.

Vascular Tissues/Fluid Tissues. The vascular tissues are of two types : blood and lymph.

(a) **Blood**. Blood consists of a watery fluid called **plasma** and **blood cells (corpuscles)** (formed elements). Blood constitutes about 8% of the total body weight. The volume of blood in an adult person is about 5.5 litres. It is a slightly alkaline fluid having *p*H 7.4.

Blood Corpuscles (Formed Elements). These constitute about 40% of the total blood. Blood corpuscles are of the following three types.

(i) **Erythrocytes** (RBCs). The shape and size of RBCs vary in different classes of vertebrates. In fish, amphibians, reptiles and birds, they are usually nucleated, oval and biconvex. But in mammals, they are biconcave, circular and **enucleated** (non-nucleated), however, camel and Llama have oval and nucleated RBCs. Human erythrocytes are 7–8 μm ($1 \mu m = 10^{-6} m$) in diameter and 2 μm thick near the rim. **Erythropoietin** is a hormone secreted by kidney cells. It stimulates the RBC production in bone narrow. Matured mammalian RBCs do not have cell organelles including nucleus, mitochondria and endoplasmic reticulum. Thus almost entire cytoplasm is filled with **haemoglobin**. Due to the absence of cell organelles, the consumption of oxygen is very low. Haemoglobin is the oxygen carrying pigment in most vertebrates except some ice fishes and eel larvae. A normal adult man and woman have 5 and 4.5 million RBCs per cubic millimetre of blood respectively. The abnormal rise in the total count of RBCs is called **polycythemia**. The increase in number of RBCs may be during muscular exercise, at high altitudes due to less availability of oxygen and at high temperature. The life of a RBC is about 120 days.

In the embryonic stage, RBCs are mainly produced by the liver and spleen. But from birth onwards, RBCs are produced by bone marrow. Iron and proteins are necessary raw materials for the synthesis of haemoglobin. However, vitamin B_{12} and folic acid stimulate the maturation of RBCs. Thus deficiency of any of these nutrients can cause anaemia.

Rouleaux. In resting and slow flowing blood, the RBCs aggregate to form **rouleaux** (the RBCs are piled on top of each other). Fibrinogen favours rouleaux formation.

(ii) **Leucocytes (WBCs)**. The leucocytes are of two types: **Agranulocytes** and **Granulocytes**. Agranulocytes include lymphocytes and monocytes. Granulocytes are eosinophils, basophils and neutrophils.

Comparison between different types of Leucocytes

Characters	*Lymphocytes*	*Monocytes*	*Eosinophils (Acidophils)*	*Basophils*	*Neutrophils*
Percentage in total leucocytes	20-30%	2-8%	1-4%	0.5-2%	60-70%
Nucleus Formation	Rounded Lymphnodes	Bean-shaped Bone marrow spleen, thymus, tonsils, and Payer's patches.	Bilobed Bone marrow	S-shaped Bone marrow	Multilobed Bone marrow

Life span	Few days or even years	10-12 hours in the blood tissue, months or even years.	14 hours	8-12 hours	10-12 hours
Functions	Antibodies formation	Phagocytic, Largest	Important role in immunity, They increase during allergy	Secretion of heparin, histamine and serotonin, Nonphagocytic	Phagocytic

The ratio of RBC : WBC is 600 : 1.

(iii) **Thrombocytes (Blood platelets)** These are really cell fragments rather than true cells. They are non nucleated, round or oval, biconvex disc-like bodies. In fact they bud off from **megakaryocytes** (very large cells formed by the bone marrow). They are 2–3 micrometres in diameter and are much smaller than both the red and white blood corpuscles. Their number normally varies from 0.15–0.45 million per micro litre of blood. When any injury is caused, the blood platelets release certain chemicals which are termed the **platelet factors** (*e.g.*, thromboplastin) which help in the coagulation of blood. Normal life span of blood platelets is about a week.

Spindle Cells These occur in all vertebrates other than mammals. Their function is similar to that of mammalian blood platelets.

Blood Clotting (Blood Coagulation). Blood clots in 2 to 8 minutes. **Prothrombin** and **fibrinogen** are two plasma proteins which are produced in the liver. These proteins are required in blood clotting. Blood plasma minus clot results in **serum** which is a pale yellow fluid. Clotting in unbroken blood vessel is called **thrombosis**

Mineral necessary for coagulation of blood is **calcium**. Vitamin K is essential for blood clotting. Recent theory of blood clotting is **cascade theory** given by **Macferlane**. According to this theory 13 factors are required for blood clotting (in which VI is hypothetical).

Anticoagulants. Any substance that prevents clotting is called **anticoagulant**. Examples : **heparin, CPD (Citrate Phosphate Dextrose), ACD (Acid Citrate Dextrose)** and **EDTA (Ethylene Diamino Tetra Acetic Acid), Oxalate, Citrate** and **Hirudin** (present in the saliva of leech).

Mucoid Tissue (= Mucous Connective Tissue) It is present in the umbilical cord. The most conspicuous component of the mucoid tissue is a jelly like substance, called **Whartson's Jelly**. Mucoid tissue also occurs in vitreous humour of the eye.

The process of formation of blood corpuscles is called **haemopoiesis** and the tissues which form blood corpuscles are termed the **haemopoietic tissues.**

Bleeding Time. It is about 1 to 6 minutes in human beings.

(b) **Lymph.** Plasma of lymph is similar to that of blood but has fewer blood proteins, less calcium and phosphorus and high glucose concentration. As regards the corpuscles, leucocytes (white blood corpuscles) are numerous, which are mainly lymphocytes. Erythrocytes and platelets are completely absent in lymph.

Lymphoid organs Besides the lymph nodes, tonsils, thymus gland, spleen and Peyer's patches are the other lymphoidal organs that secrete lymph. Liver also produces lymph.

Functions of Lymph. Lymph acts as a "middle man" which transports oxygen, food materials, hormones, etc., to the body cells and brings carbon dioxide, waste products, etc., from the body cells to blood and then finally pours the same into the venous system. Phagocytes of the lymph nodes engulf and destroy bacteria and other foreign substances. It transports fatty acids, glycerol and fat soluble vitamins from the intestine by **lacteals** (lymph capillaries).

Debove's membrane. It is a layer of connective tissue cells between the epithelium and basement tissue.

III. MUSCULAR TISSUE

Origin. Muscular tissues develop from the mesoderm of the embryo. Iris muscles of eye develop from ectoderm.

Types. 1. **Skeletal Muscle.** It is closely attached to the skeletal bones. It found in the muscle of limbs, body walls, tongue, pharynx and beginning of oesophagus and are under the control of animal's will. Each skeletal muscle consists of numerous muscle fibres. Each muscle fibre is an elongated cell, which is **syncytial** (multinucleate). Its membrane is called **sarcolemma.** Each muscle fibre contains many **myofibrils**.

A myofibril has dark and light bands. The dark bands are also called **A-bands.** The light bands are also called **I-bands**. Each I–band has at its centre a dark membrane called **Z-line.** The part of the myofibril between two Z-lines is called **sarcomere**. Thus, each sarcomere is a bundle of **thick** and **thin myofilaments**. The thick filament consists mainly of **myosin** protein. The thin filament is composed of three different proteins – **actin, tropomyosin** and **troponin**.

2. **Smooth Muscle.** It is found in the oesophagus (posterior part), stomach, intestine, lungs, urinogenital tract, urinary bladder, blood vessels, iris of eye, dermis of skin and arrector pili muscle of hair. It is involuntary in function.

Functionally smooth muscle is of two types: (i) **Single-unit smooth muscle** is found in the walls of hollow visceral organs like gastrointestinal tract and urinary bladder. (ii) **Multi-unit smooth muscles** is found in arrector pili muscles of skin dermis, ciliary and iris muscles in the eyes, and muscle of the walls of the large blood vessels.

3. **Cardiac Muscle.** This muscle is found in the wall of heart and has very rich blood supply. Cardiac muscle is uninucleate, involuntary, divided at places by **intercalated discs**. The fibres have some lateral branches, known as **cross bridges**. It is supplied with both central and autonomic nervous system and is not under the control of the will of the animal. However, this muscles never gets fatigued. It has the property of contraction, even when it is isolated from the body temporarily.

Human heart is **myogenic.** It means cardiac impulses originate from the SA mode (a node of specialized cardiac muscle fibres situated in the wall of the heart).

IV. NEURAL TISSUE

Origin. Neural tissue develops from the ectodoerm of the embryo. Except microglia which develop from mesoderm.

Special properties. The special properties of the cells of the neural tissues are **excitability** and **conductivity**. The cells of neural tissue are specialized for receiving stimuli and transmitting message.

Neural tissue consists of neurons and neuroglia.

Neurons (Nerve cells). Structural and functional units of neural tissue are called **neurons**.

A neuron is differentiated into two parts : cyton and neurites.

(i) **Cyton** (Cell body, Soma, Perikaryon). The cyton contains cytoplasm **(neuroplasm)**, nucleus mitochondria, Golgi bodies, rough endoplasmic reticulum, ribosomes, lysosomes, fat globules, etc. Besides these, presence of **Nissl granules** and **neurofibrils** is characteristic to all neurons. Nissl granules are irregular masses of ribosomes and rough endoplasmic reticulum. They probably synthesize proteins in the cell. Neurons lack a centrosome.

(ii) **Neurites.** The processes of neurons are called neurites. The latter are of two types : **dendrons** or **dendrites** and an **axon** or **axis cylinder**. The part of cyton from where the axon arises is

called **axon hillock**. The axon ends in a group of branches, **the terminal arborizations** (axon endings). Certain axons also give rise to side branches, called **collateral fibres**. The neuroplasm of axon contains abundant neurofirbils and mitochondria but Nissl granules, Golgi bodies, ribosomes and fat globules are absent.

Synapse. The region of union of the terminal arborization of the axon of one neuron with the dendrites of another neuron is called **synapse**. Impulses are transferred from one neuron to the next neuron through synapse.

Types of Neurons. (A) On the basis of the structure, the neurons are of **three** types : (i) **Unipolar neurons**. They occur in the neural system* of embryos. (ii) **Bipolar neurons**. They occur in the retina of eye. (iii) **Multipolar neurons**. They occur in the neural system of adults.

(B) Neurons can be classified according to their functions as follows : (i) **Sensory or afferent Neurons**. (ii) **Motor or efferent neurons**. (iii) **Interneurons or Adjustor neurons**. They are present in the central neural system (brain and spinal cord).

Nerve Fibres. (a) On the basis of structure the nerve fibres are of two types :

(i) **Medullated** (myelinated) **nerve fibres**. These are found in the brain, spinal cord, cranial and spinal nerves. They have **myelin sheath, nodes of Ranvier** and **Schwann cells**. In the central neural system these fibres form white matter. Saltatory conduction occurs in medullated nerve fibres. (ii) **Non-medullated** (nonmyelinated) **nerve fibres**. These are found in the autonomic neural system. In the central neural system these fibres form grey matter.

(b) Functionally, the nerve fibres are again of two types :

(i) **Afferent or sensory fibres** and (ii) **Efferent or motor fibres.**

Nerve impulses pass between neurons through the synapse with the help of chemicals which are called neurotransmitters such as **acetylcholine**.

A nerve is a bundle of numerous nerve fibres which are separated into several small bundles, termed **fasciculi**. The latter are bound together by a vascular connective tissue, the **epineurium**. The epineurium also forms a sheath around the nerve itself. Each fascicule is surrounded by another connetive tissue called **perineurium**. Inside the fascicule, its fibres are bound together by another connective tissue called **endoneurium**.

Neuroglia or neuroglial cells are specialised cells found in the brain and spinal cord supporting the neurons and their fibres. Neuroglia are more than one half the volume of neural tissue in human body. They are divided into two major categories : Macroglia (= large glial cells) and microglia (= small glial cells). **Macroglia** are of two types : (i) **Astrocytes**. There are two types of astrocytes (a) **Fibrous astrocytes** are found chiefly in the white matter. (b) **Protoplasmic astrocytes** occur chiefly in the grey matter. The astrocytes provide the repair mechanism and replace lost tissue. (ii) **Oligodendrocytes**. They are found in close association with large nerve cells, and in rows between bundles of fibres in the white matter. They play a metabolic role in the formation and preservation of myelin sheath of the nerve fibres in the central neural system. **Microglia** are found diffusely through both grey and white matter. Microglia are mesodermal in origin. These cells are the scavengers of the neural system and become phagocytic in case of injury and death of the other elements.

Ependymal cells and neurosecretory cells are also part of neural tissue.

Ependymal cells. These cells form cellular membrane that lines the ventricles (cavities of the brain) and the central canal of the spinal cord. Their free surface bears numerous microvilli and cilia. The microvilli help in the absorption of cerebrospinal fluid. The movements of cilia contribute the flow of cerebrospinal fluid.

... system

Neurosecretory cells (Neurosecretory neurons). These occur in the neural system. The hyothalmic neuro-secretory cells are present in the hypothalamus (part of the brain). They release **neurohormones** (releasing factors) into the blood stream. These hormones are carried to the anterior lobe of the pituitary gland where they regulate the secretion of hormones such as ACTH, TSH, GH, LH, FSH and prolactin.

READ AND DIGEST

- Epithelial tissues first evolved during the course of evolution.
- Ageing of animal is associated with deterioration in its connective tissues.
- Collagenous fibres are the most abundant fibrous elements of areolar and other connective tissue proper.
- **Osteoclasts.** These are derived from osteoblasts and osteocytes. They are rich in *acid phosphates* and destroy the bone.
- **Brown fat.** It is found in hibernating mammals such as rats and other rodents and in new born human babies. The fat cells of brown fat contain a large number of mitochondria. Therefore, brown fat has an oxidation power 20 times more than that of yellow fat.
- Amphibian RBCs are the largest among the vertebrates. Those of *Amphiuma and Proteus* are the largest among amphibians. Mammals have smallest RBCs among the vertebrates. Those of musk deer are the smallest among the mammals.
- Concave surface of mammalian RBCs is helpful in increasing surface area of RBCs.
- Total count of WBC varies from 5,000 to 10,000 per cubic millimetre of blood in humans.
- Leucocytes in general and lymphocytes in particular are capable of squeezing out through the wall of the blood capillaries into the extra vascular region. This phenomenon is called **diapedesis**.
- Platelets occur only in mammals.
- **Myoblasts** are muscle forming cells.
- Sarcomere is the functional unit of the muscle.
- The cardiac muscles have a unique property of spontaneous development of an electrical depolarisation (action potential) in their fibres for causing their own contraction.
- Cardiac muscles are known as myocardium.
- During foetal life and at birth there is red bone marrow throughout the skeleton. After about the fifth year the red bone marrow is gradually replaced in the long bones by yellow bone marrow. *By 20 to 25 years the red bone marrow persists only in the vertebrae, sternum, ribs, claviceps, scapulae, pelvis, cranial bones and in the proximal ends of femora (pl. of femur) and humeri (pl. of humerus). In old age, the bone marrow of the cranial bones undergo degeneration and is then called* **gelatinous marrow.**
- Largest cells of the body — Nerve cells.
- Least Regeneration Power — Neural tissue.
- Haemocyanin is a copper containing respiratory pigment occuring in arthropods and malluscs. It is much less efficient oxygen carrier.
- Monocytes — Largest, most active phagocytic WBCs.
- Eosinophils — Phagocytic, high eosinophils count indicates allergic reaction.
- Basophils — Nonphagocytic, involved in allergic reactions, release histamine and heparin.
- Neutrophils — most acitve phagocytic WBCs.
- Lifespan of WBCs in man is about 10–13 days.
- The process by which blood cells are formed is called **haemopoiesis** Yolk sac forms blood cells in the early stage of development.
- **Osteoclasts** are the bone dissolving cells.
- **Diaphysis.** It is the shaft or long main portion of a bone.
- **Epiphyses.** These are the extremities or ends of the bone.

MULTIPLE CHOICE QUESTIONS

1. Who established Histology as a separate branch of Zoology ?
(1) Marcello Malpighi (2) Leeuwenhoek
(3) Robert Hooke (4) Stanley
2. From evolution point of view, the tissue which originated first was
(1) Connective tissue
(2) Epithelial tissues
(3) Muscular tissue (4) Nervous tissue
3. Cells lining the blood capillaries are called
(1) oxyntic cells (2) endothelial cells
(3) parietal cells (4) haemocytes.
4. Stria vascularis is a special epithelium which is present in
(1) retina of eye (2) pinna of ear
(3) cochlea of internal ear
(4) nose
5. The wall of coelom is formed of epithelium called
(1) columnar (2) squamous
(3) glandular (4) ciliated
6. The cells of endothelium and mesothelium become wavy and are called
(1) syncytial (2) acellular
(3) tessellated (4) polygonal
7. Brush border is the peculiarity of
(1) secretory cells (2) nerve cells
(3) absorptive cells (4) blood cells
8. Glands in a vertebrate body may originate from
(1) ectoderm (2) mesoderm
(3) ectoderm and endoderm
(4) ectoderm, mesoderm and endoderm.
9. Presence of extracellular basement membrane is the peculiarity of
(1) epithelial tissue
(2) connective tissue
(3) nervous tissue (4) muscular tissue
10. The epithelium found in the lining layer of stomach and intestine is
(1) columnar (2) squamous
(3) stratified (4) pseudostratified.
11. Endothelium lining a blood vessel is formed of
(1) ciliated epithelium
(2) columnar epithelium
(3) cuboidal epithelium
(4) simple squamous epithelium.
12. Germinal epithelium of ovary is formed of
(1) columnar epithelium
(2) squamous epithelium
(3) cuboidal epithelium
(4) stratified epithelium
13. Epithelium forming the inner layer of urinary bladder is
(1) simple squamous (2) transitional
(3) simple columnar (4) neurosensory
14. Which of the following is a holocrine secretion ?
(1) Mammary (2) Sebaceous
(3) Pancreas (4) Sweat glands
15. In which portion of uriniferous tubule, (nephron) the lumen is lined with brush-border microvilli ?
(1) Proximal convoluted tubule
(2) Distal tubule
(3) Collecting tubule (4) Loop of Henle
16. Zymogen cells are found in
(1) stomach (2) brain
(3) kidney (4) liver
17. True coelom is covered by
(1) ectoderm (2) endoderm
(3) mesoderm (4) both (1) and (2)
18. Nonkeratinised stratified squamous epithelium is found in
(1) epidermis of skin of land vertebrates.
(2) oral cavity and pharynx
(3) vagina and cervix (4) both (2) & (3)
19. Salivary glands are
(1) merocrine (2) apocrine
(3) holocrine (4) heterocrine
20. Fibrous tissue which connects bones is
(1) tendon (2) adipose tissue
(3) ligament (4) connective tissue
21. Which tissue is widely distributed in the body and also forms most of the parts of body ?
(1) Connective tissue (2) Muscular tissue
(3) Nervous tissue (4) Epithelial tissue
22. Collagen fibres are found maximum in
(1) ligaments (2) tendons
(3) bone (4) cartilage

23. Plasma cells synthesize
(1) enzymes (2) hormones
(3) mucus (4) antibodies

24. Pericardium of heart is composed of
(1) yellow elastic tissue
(2) white fibrous tissue
(3) reticular tissue (4) areolar tissue

25. Tendons connect
(1) nerve to muscle
(2) muscle to muscle
(3) bone to bone
(4) bone to muscle

26. The vermiform appendix is made up of
(1) digestive tissue (2) respiratory tissue
(3) excretory tissue (4) lymphatic tissue

27. The commonest cartilage to ossify is
(1) hyaline (2) elastic
(3) fibrous (4) fibroelastic

28. Mast cells found in areolar tissue secrete
(1) serotonin (2) heparin
(3) histamine (4) all of these

29. Areolar connective tissue joins
(1) bone with bone
(2) fat body with muscles
(3) integument with muscles
(4) bone with muscles

30. Elastic cartilage is found in
(1) the auditory tube, larynx and pinnae of mammals
(2) the trachea
(3) intervertebral discs
(4) none of the above.

31. Which is the strongest cartilage ?
(1) Fibrous cartilage (2) Elastic cartilage
(3) Cartilage of pinna
(4) Hyaline cartilage

32. Hyoid apparatus is composed of
(1) hyaline cartilage (2) fibrous cartilage
(3) calcified cartilage (4) elastic cartilage

33. Intervertebral discs are composed of
(1) hyaline cartilage (2) elastic cartilage
(3) fibrous cartilage (4) none of these

34. The ends of the bones of limbs are composed of which cartilage ?
(1) Fibrous (2) Hyaline
(3) Elastic (4) Calcified

35. Which salt is found in maximum quantity in bones ?
(1) Calcium carbonate
(2) Calcium phosphate
(3) Sodium chloride
(4) Magnesium chloride

36. If bone is kept for three days in 10% KOH sol; it will
(1) be unaffected (2) dissolve
(3) soften (4) break

37. Mammalian bone is different from cartilage in
(1) collagen fibres (2) blood vessels
(3) lymph vessels (4) Haversian canals

38. Which of the following cells are responsible for dissolving the bone matrix ?
(1) Osteocytes (2) Osteoblasts
(3) Osteoclasts (4) Osteons

39. Bone forming cells are
(1) osteoblasts (2) osteoclasts
(3) chondroclasts (4) chondroblasts

40. The bone of mammal contains longitudinal Haversian canals which are connected by transverse canals, known as
(1) Semi-circular canals
(2) Volkman's canals
(3) Inguinal canal
(4) Bidder's canals.

41. The bone marrow is composed of
(1) muscle fibres and adipose tissue
(2) areolar tissue and adipose tissue
(3) adipose tissue and calcified cartilage
(4) adipose tissue, areolar tissue and blood vessels.

42. Largest erythrocytes are found in
(1) man and monkey
(2) fish and frog
(3) *Amphiuma* and *Proteus*
(4) lizard and snake

43. Normally haemopoiesis in frog occurs in
(1) liver and spleen (2) liver
(3) spleen (4) bone marrow

44. Which of the following has longest life in blood ?
(1) Eosinophil (2) Neutrophil
(3) RBC (4) Basophil

45. What is the main difference in human and frog RBC ?
(1) Human RBC are nonnucleated

(2) Haemoglobin is found only in human RBC
(3) Human RBC have nucleus
(4) Human RBC are multinucleate

46. Which is important in blood clotting ?
(1) Plasma (2) RBC
(3) WBC (4) Thrombocytes

47. In normal healthy female, the number of RBC/mm^3 of blood is
(1) 6.5–7.0 million (2) 5.5–6.0 million
(3) 4.5–5.0 million (4) 3.5–4.0 million

48. Blood clotting occurs with the help of
(1) prothrombin (2) calcium ions
(3) fibrinogen (4) all of these

49. Concave surface of mammalian RBCs is helpful in
(1) formation of more haemoglobin
(2) increasing surface area of RBCs
(3) reducing surface tension of plasma membrane.
(4) providing more space for haemoglobin

50. Which of the following is an anticoagulant and checks blood coagulation in blood vessels ?
(1) Prothrombin (2) Globulin
(3) Thromboplastin (4) Heparin

51. Vitamin K is required for
(1) formation of thromboplastin
(2) conversion of fibrinogen to fibrin
(3) conversion of prothrombin to thrombin
(4) synthesis of prothrombin

52. Ratio of RBCs and WBCs in human being is
(1) 300 : 1 (2) 500 : 3
(3) 7 : 4 (4) 600 : 1

53. *p*H of human blood is
(1) 6.4 (2) 7.4 (3) 8.4 (4) 5.4

54. Spindle cells are found in the blood of
(1) mammals
(2) fishes and amphibians
(3) reptiles and birds
(4) both (2) and (3)

55. Cartilage is
(1) nonvascular (2) poorly vascular
(3) highly vascular (4) none of these

56. The light and dark bands are visible in
(1) striped muscles
(2) cardiac muscles
(3) unstriped muscles
(4) both (1) and (2)

57. Cardiac muscle is structurally different from smooth muscle because it
(1) is branched (2) is involuntary
(3) has a single nucleus
(4) does not fatigue.

58. Nerve cells do not divide because they do not have
(1) nucleus (2) golgi body
(3) centrosome (4) mitochondria

59. Structurally what are olfactory nerve cells ?
(1) Bipolar neurons
(2) Unipolar neurons
(3) Multipolar neurons
(4) Neurochemically specialized neurons

60. Which cartilage is present in trachea, larynx and bronchi ?
(1) Hyaline (2) Fibrous
(3) Elastic (4) Calcifed

61. Striated muscles contract because of
(1) sliding of myosin rods on actin rods
(2) sliding of actin rods on myosin rods
(3) actin rods coming close to each other
(4) myosin rods coming close to each other

62. *A* bands and *I* bands are found in
(1) voluntary muscles
(2) involuntary muscles
(3) unstriated muscles
(4) striated muscles

63. Sarcolemma is a membrane found over
(1) nerve fibre (2) cardiac muscle
(3) muscle fibre (4) heart

64. Sarcomere is the area between two
(1) *H* zones (2) *Z* lines
(3) *A* bands (4) *I* bands

65. Smooth muscles are
(1) involuntary, spindle shaped, uninucleated, tapering
(2) voluntary, multinucleate, cylindrical
(3) involuntary, cylindrical, multinucleate
(4) voluntary, branched, uninucleate.

66. Cardiac muscles contract
(1) quickly and they fatigue
(2) rhythmically and are unfatigued
(3) slowly and are not fatigued
(4) slowly and they fatigue.

67. Large number of mitochondria are found in
(1) thigh muscle (2) cardiac muscle
(3) breast bone of bird
(4) all of the above.

68. Which element is essential for muscle contraction ?
(1) Na^+ (2) K^+ (3) Mg^+ (4) Ca^+

69. Muscles get fatigued due to accumulation of
(1) adenosine triphosphate
(2) CO_2
(3) lactic acid
(4) phosphate molecules

70. The sarcomere is structural and functional unit of a muscle fibre and comprises
(1) *A* band and *I* band
(2) *A* band and half of each adjacent *I* band
(3) *A* band and half *I* band
(4) Half *A* band and complete *I* band.

71. Strongest muscles in human body are found in
(1) jaws (2) thighs
(3) neck (4) hands

72. The oblique cross connections to form a contractile net work of fibres and the intercalated discs are characteristically found in
(1) striated muscle (2) unstriated muscle
(3) cardiac muscle (4) radial muscle

73. SKeletal muscles are attached to bones except in
(1) jaw and nose
(2) nose and pinnae
(3) tongue and oesophagus
(4) pinnae and nose.

74. Iris muscles of eye are formed from
(1) mesoderm (2) endoderm
(3) ectoderm (4) both (1) and (2)

75. Nodes of Ranvier are found in
(1) cyton (2) nephrons
(3) axon (4) telodendria

76. Each nerve fibre in a nerve is surrounded by a layer of connective tissue, known as
(1) epineurium (2) perineurium
(3) endoneurium (4) exoneurium

77. Chemical substance secreted at the synapse and helpful in passing impulse from neuron through a gap is
(1) Acetylcholine (2) ATP
(3) Cholecytokinin (4) Cholesterol

78. Schwann's Cells and Nodes of Ranvier are found in
(1) Neurons (2) Osteoblasts
(3) Chondroblasts (4) Gland cells

79. Nissl's granules are irregular masses of ribosomes and RER and are characteristically found in.
(1) nerve cells
(2) mast cells
(3) bone cells (osteocytes)
(4) cartilage cells (chondrocytes)

80. Neurosecretoy cells secrete
(1) enzymes (2) releasing factors
(3) mucus (4) sweat

81. Ependymal cells are found in the
(1) ventricles of brain
(2) central canal of spinal cord
(3) retina of eye
(4) both (1) and (2)

82. In the central neural system, medullated nerve fibres form
(1) white matter (2) grey matter
(3) interneurons (4) neurons

83. Nodes of Ranvier are
(1) areas of swellings of axons
(2) areas where myelin sheath of nerve touches the axon
(3) nodes formed in skeletal muscles
(4) areas found in the stomach wall.

84. Neuroglia cells are
(1) astrocytes (2) oligodendrocytes
(3) microglia (4) all of these

85. Collateral fibres are given out along its way in
(1) muscle fibre (2) axon
(3) dendron (4) dendrites

86. Myelin sheath is made up of phospholipids and is present around the
(1) non-medullated nerve fibre
(2) medullated nerve fibre
(3) medullated and non- medullated nerve fibres
(4) muscle fibres

87. Unipolar neurons are present in
(1) central nervous system
(2) peripheral nervous system
(3) autonomic nervous system
(4) neural system of embryo.

88. Bipolar nerve cells are present in
(1) skin tactile corpuscles
(2) spinal cord
(3) retina of eye
(4) all of the above

89. Multipolar nerve cells are present in
(1) cochlea
(2) dorsal root ganglia of spinal cord
(3) retina of eye
(4) brain

90. Neurosecretory cells are found in .... of the brain
(1) Medulla oblongata (2) Olfactory lobes
(3) Hypothalamus (4) Pons varolii

91. Myelin sheath in CNS is synthesized by
(1) oligodendrocytes (2) Schwann cells
(3) microglia (4) all of these.

92. Nissl's granules are absent in
(1) Dendrons and dendrites
(2) Cyton
(3) Axon
(4) Dendrons and cyton.

93. The Word 'tissue' was given by
(1) Mayer (2) Bichat
(3) Malpighi (4) Wilson

94. Reticular cells are
(1) secretory (2) respiratory
(3) excretory (4) phagocytic

95. A Haversian canal with its surrounding lamellae and osteocytes constitutes a cylindrical unit of bone called
(1) periosteum (2) endosteum
(3) osteon (4) haversian

96. In camel, erythrocytes are
(1) circular, biconcave, non-nucleated
(2) oval and nucleated
(3) circular, biconcave and nucleated
(4) oval and non-nucleated

97. In embryonic stage, erythrocytes develop from
(1) bone marrow (2) liver and kidney
(3) spleen and kidney (4) liver and spleen

98. Bone marrow occurs in
(1) ribs and sternum
(2) ribs, sternum and cranial bones
(3) ribs and cranial bones
(4) only ribs

99. Life span of human white blood corpuscles is
(1) 24 hours (2) less than 10 days
(3) 120 days (4) 100 hours

100. Which one is a factor for maturation of erythrocytes ?
(1) Vitamin B12 (2) Vitamin A
(3) Vitamin D (4) Vitamin C

101. The main cause of anaemia is
(1) deficiency of Ca (2) deficiency of Fe
(3) deficiency of Na (4) deficiency of Mg

102. Which is the prinicpal cation in the plasma of the blood ?
(1) Calcium (2) Sodium
(3) Potassium (4) Magnesium

103. Match the types of animal tissues listed under column-I with the location given under column-II; choose the answer which gives the correct combination of the alphabets of the two columns.

Column I (Tissues)	*Column II (Location)*
A. Simple columnar epithelium	p. Wall of heart
B. Cardiac muscle	q. bone joints
C. Adipose tissue	r. Inner lining of stomach and intestine
D Hyaline cartilage	s. Below the skin in the abdomen, buttocks, thighs and breasts
	t. Diaphragm

(1) A = r, B = t, C = q, D = s
(2) A = r, B = p, C = s, D = q
(3) A = r, B = p, C = t, D = s
(4) A = p, B = r, C = s, D = t

104. Match the terms listed under column-I with the structures which they occur given under column-II; choose the answer which gives the correct combination of alphabets of the two columns.

Column I (Structure)	*Column II (Occurrence)*
A Haversian canal	p. Kidney
B. Dendrites	q. Cartilage
C. Sarcolemma	r. Muscle
D Chondrocytes	s. Nerve cells
	t. Bone

(1) A = p, B = r, C = s, D = t
(2) A = q, B = r, C = s, D = t
(3) A = s, B = t, C = q, D = r
(4) A = t, B = s, C = r, D = q

105. Bone marrow is absent in the bones of
(1) fish (2) birds
(3) reptiles (4) frog

106. Which of the following statements is correct for node of Ranvier of nerve ?
(1) Neurilemma is discontinuous
(2) Myelein sheath is discontinuous
(3) Both neurilemma and myelein sheath are discontinuous
(4) Covered by Myelein sheath

107. What will happen if ligaments are cut or broken?
(1) Bones will move freely at joints
(2) No movement at joint
(3) Bone will become unfix
(4) Bone will become fixed

*108. Which is anticoagulated in blood-cell counting?
(1) CH_3COOH (2) H-CHO
(3) EDTA* (4) C_6H_6
(5) HCl

109. Which of the following contains the largest quantity of extracellular material ?
(1) Striated muscle (2) Areolar tissue
(3) Stratified epithelium
(4) Myelinated nerve fibres

110. Adjacent cells are interconnected by
(1) desmosomes (2) vacuoles
(3) mitochondria (4) E.R.

111. Find out the *wrongly* matched pair
(1) *Squamous epithelium* – Skin of frog
(2) *Columnar epithelium* – Peritoneum of body cavity
(3) *Ciliated epithelium* – Bronchioles
(4) *Stratified cuboidal epithelium* – Oesophagus
(5) *Glandular epithelium* – Salivary gland

112. Which one of the following pairs of structures distinguishes a nerve cell from other types of cell ?
(1) Flagellum and medullary sheath
(2) Nucleus and mitochondria
(3) Perikaryon and dendrites
(4) Vacuoles and fibres

113. In a vertebrate which germ layer forms the skeletal muscles ?
(1) Ectoderm (2) Endoderm
(3) Mesoderm (4) Both (1) and (3)

114. Largest muscle in the human body is
(1) sartorius (2) gluteus
(3) stapedius (4) masseter

115. The most abundant type of WBCs (granulocytes) in human blood are
(1) Basophils (2) Neutrophils
(3) Monocytes (4) Eosinophils

116. Platelets are formed from the
(1) erythropoietin (2) osteoclasts
(3) megakaryocytes (4) melanocytes

117. Select a unicellular gland
(1) goblet cell (2) gastric gland
(3) chromophil cell (4) chloragogen cell

118. An example of embryonic connective tissue is
(1) Wolman's jelly (2) Wright's jelly
(3) Wharton's jelly (4) none of these

119. Short life span is of
(1) Lymphocytes (2) Monocytes*
(3) Basophils (4) Neutrophils

120. Haversian canal is found in
(1) epiphysis of femur of mammals
(2) diaphysis of humerus of mammals
(3) internal ear of mammals
(4) obturator foramen

121. Metals required in synthesis of haemoglobin are
(1) iron (2) copper
(3) cobalt (4) all of these

*122. Which cell is called 'medusa cell' ?
(1) lymphocyte (2) eosinophil
(3) basophil (4) neutrophil

123. Sarcolemma is absent in .... muscle fibres
(1) skeletal (2) smooth
(3) cardiac (4) Both (2) and (3)

*108. EDTA– Ethylene Diamine Tetra Acetic Acid.
*10–20 hours

124. Neurolimma is
(1) cell membrane of neuron
(2) plasma membrane of axon
(3) cytoplasm of nerve cell
(4) cytoplasm of Schwann's cell

125. Phagocytic cells present in brain are
(1) Kupffer cells (2) monocytes
(3) microglia (4) macrophages

126. Target organ of *Mycobacterium leprae*
(1) Medullary sheath
(2) Presynaptic nodes
(3) motor end plates (4) Schwann cells

127. Which of the following acts as 'middle man of the body' ?
(1) Plasma (2) Lymph
(3) WBC (4) RBC

128. In a bone, concentric layers of matrix are called
(1) Haversian canals
(2) Volkmann's canal
(3) lacunae (4) lamellae

129. Wrinkles in old age are due to
(1) myosin fibres (2) actin fibres
(3) collagen fibres (4) none

130. Which of the following are not true cells in the blood ?
(1) Platelets (2) Monocytes
(3) Neutrophils (4) Basophils

131. Which of the following coagulating factor of blood is hypothetical ?
(1) Accelerin (VI)
(2) Chritmas factor (IX)
(3) Stuart – Prower factor (X)
(4) Fibrin stabilizing factor (XIII)

132. Spongy or cancellous bones are
(a) skull bones (b) vertebrae
(c) femur (d) ribs

(1) a and b are correct
(2) b and d are correct
(3) a and c are correct
(4) a, b and c are correct

133. The condition in which the potassium levels is increased is known as
(1) osteomalacia
(2) hyperkalaemia
(3) hyperexcitability
(4) hypercholesterolaemia

134. Microglia are .... in origin
(1) endodermal (2) mesodermal
(3) endodermal (4) both (1) and (3)

135. Apocrine secretion of gland means
(1) when the product is released the cell remains intact
(2) entire contents of cell is discharged with the destruction of cell
(3) when part of apical cytoplasm is lost
(4) none of these

136. Red bone marrow occurs in memrbanous bones such as
(1) all flat bones of skull, vertebrae, sternum and ribs
(2) only in centrum of vertebrae
(3) only in centrum of vertebrae and skull
(4) non of these

137. Schneiderian epithelium is found in
(1) nasal passage (2) trachea
(3) retina
(4) Bowman's capsule

138. Polycythemia refers to an abnormal increase in the number of
(1) eosinophils (2) lymphocytes
(3) plasma cells (4) erythrocytes

139. The bundles of nerves fibres are called
(1) fasciculi (2) epineurium
(3) perineurium (4) neurilemma

140. Processes from osteoblasts are found in
(1) lamella (2) canaliculi
(3) dendrites (4) Haversian canals

141. The most abundant kind of cartilage in the body is
(1) elastic cartilage (2) fibro cartilage
(3) hyaline cartilage (4) none of these

142. The softest tissue in the body is
(1) nerve (2) muscle
(3) blood (4) skin

143. The main difference between white and yellow fibres is of
(1) protein (2) colour of fibres
(3) both (1) and (2) (4) none of these

144. Cardiac muscles are
(a) striated (b) nonstriated
(c) voluntary (d) involuntary

(1) a and c are correct
(2) b and d are correct

(3) a and d are correct
(4) a, b and c are correct

145. Which of the following statements is true for lymph ?
(1) WBCs and serum
(2) RBCs, WBCs and plasma
(3) RBCs proteins and platelets
(4) All components of blood except RBCs and some proteins

146. The largest RBCs have been seen in
(1) Man (2) Whale
(3) Amphibia (4) Elephant

147. Mark the odd one out
(1) Monocytes (2) Neutrophils
(3) Lymphocytes (4) Erythrocytes

148. Pernicious anaemia is due to the deficiency of
(1) iron (2) cobalamin
(3) calciferol (4) phylloquinone

149. The type of tissue lining the nasal passage, bronchioles and Fallopian tubes is
(1) columnar ciliated epithelium
(2) cuboidal epithelium
(3) neurosensory epithelium
(4) germinal epithelium
(5) stratified columnar epithelium

150. Ligament is mainly made up of
(1) reticulin (2) elastin
(3) myosin (4) collagen

151. Action potential is generated by
(1) Na^+ (2) K^+
(3) Ca^+ (4) Cl^-

152. Which is immortal ?
(1) Plasma cell (2) Germ cell
(3) Brain cell (4) Kidney cell

153. Leukocytes can squeeze out of blood capillaries. This process is called
(1) reucocytosis (2) thrombopoiesis
(3) diapedesis (4) haemopoiesis

154. Keratinized dead layer of skin is made of
(1) stratified squamous
(2) simple cuboidal
(3) simple columnar
(4) stratified columnar

155. The haemoglobin of human foetus
(1) has only two protein subunits instead of four
(2) has a lower affinity for oxygen than that of an adult
(3) its affinity for oxygen is the same as that of an adult
(4) has a higher affinity for oxygen than that of an adult

156. Which type of white blood cells are concerned with the release of histamine and the natural anticoagulant heparin ?
(1) Basophils (2) Monocytes
(3) Neutrophils (4) Eosinophils

157. The most active phagocytic white blood cells are
(1) neutrophils and monocytes
(2) neutrophils and eosinophils
(3) eosinophils and lymphocytes
(4) lymphocytes and macrophages

158. Debove's membrane is layer of
(1) muscular tissue
(2) epithelial tissue
(3) connective tissue
(4) all of these

159. Notochord, skeletal system and dermis of the skin are the derivatives of
(1) endoderm (2) ectoderm
(3) mesoderm
(4) all the three layers

160. Curved portion of the Henle's loop of the nephrons are lined by
(1) columnar epithelium
(2) squamous epithelium
(3) ciliated epithelium
(4) cuboidal epithelium

161. Which of the following groups consists of organs having innermost lining of *Colunnar epithelium* ?
(1) Stomach, Fallopian tube, lung, alveoli
(2) Gall bladder, stomach artery
(3) Intestine, gastric gland, gall bladder
(4) Gastric gland, pancreatic duct, veins

162. In thyroid follicle which type of epithelial tissue is present ?
(1) Squamous (2) Cuboidal
(3) Transitional (4) Columnar

163. Which of the following statements is true ?
(1) Saltatory conduction is seen in non-myelinated nerve fibres
(2) Nissl's granules are found in muscle fibres

(3) Non-myelinated nerve fibres do not possess nodes of Ranvier
(4) Non-myelinated nerve fibres are completely enclosed by myelin sheath

164. Identify the correctly matched pair/pairs of the germ layers and their derivatives.
A. ectoderm – epidermis
B. endoderm – dermis
C. mesoderm – muscles
D. mesoderm – notochord
E. endoderm – enamel of teeth
(1) A and D only (2) A and B only
(3) A, C and D only (4) A, B, C and E only

165. The size of pupil is controlled by the
(1) ciliary muscles
(2) suspensory ligaments
(3) cornea
(4) Iris muscles

166. Skeletal muscles are controlled by
(1) sympathetic nerves
(2) parasympathetic nerves
(3) somatic nerves
(4) autonomic nerves

167. Cells that maintain marrow cells are called
(1) osteocytes (2) chondrocytes
(3) osteoclasts (4) none of these

168. Match list I with list II and find the correct option

List I (Epithelial tissue)	List II (Location)
1. Cuboidal	(A) Epidermis of skin
2. Ciliated	(B) Inner lining of blood vessel
3. Columnar	(C) Inner surface of gall bladder
4. Squamous	(D) Inner lining of Fallopian tube
5. Keratinized squamous	(E) Linig of pancreatic duct

(1) 1 – E, 2 – D, 3 – B, 4 – C, 5 – A
(2) 1 – C, 2 – D, 3 – E, 4 – B, 5 – A
(3) 1 – E, 2 – D, 3 – C, 4 – B, 5 – A
(4) 1 – C, 2 – D, 3 – E, 4 – A, 5 – B
(5) 1 – C, 2 – E, 3 – D, 4 – A, 5 – B

169. Myelin of the nerve fibres of the central nervous system is produced and maintained by
(1) oligodendrocytes (2) astrocytes
(3) microglia (4) Schwann cells

170. The type of connective tissue that is associated with the umbilical cord is
(1) areolar connective tissue
(2) jelly-like connective tissue
(3) adipose connective tissue
(4) reticular connective tissue

171. Note the following
(A) It forms the lining of the cavities of alveoli of the lungs
(B) it forms the lining of wet surfaces like buccal cavity and oesophagus
(C) it occurs in the ducts of sweat glands
(D) it forms the lining of salivary glands and sweat glands
(E) it is a loose connective tissue
Which of the above are associated with simple epithelial tissue ?
(1) A and D (2) B and C
(3) C and A (4) D and E

172. The wall of the internal organs such as blood vessels, stomach and intestine contains which type of muscle tissue?
(1) Smooth muscle fibre
(2) Cardiac muscle fibre
(3) Skeletal muscle fibre
(4) Neural tissue

173. The matrix of bone and cartilage can be distinguished by the presence of
(1) haversian canal
(2) lacuna
(3) chromatophores
(4) adipose cells *(Orissa JEE 2010)*

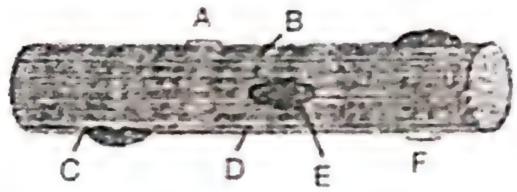
174. Multi-lobed nucleus and granular cytoplasm are characteristics of which of the following types of WBCs ?
(1) neutrophils (2) monocytes
(3) lymphocytes (4) eosinophils
(Orissa JEE 2010)

175. In the human brain, the total number of glial cells
(1) is significantly greater than number of neurons
(2) is significantly lower than the neurons
(3) roughly equals the number of Schwann cell
(4) roughly equals the number of neurons.
(Chandigarh CET 2010)

176. Which type of epithelium is involved in a function to move particles or mucus in direction?
(1) Ciliated epithelium
(2) Columnar epithelium
(3) Squamous epithelium
(4) Cuboidal epithelium *(HP PMT 2010)*

177. The cells lining the blood vessels belong to the category of
(1) connective tissue
(2) smooth muscle tissue
(3) squamous epithelium
(4) columnar epithelium
(AIPMT (Mains) 2011)

178. The diagram given below represents the histology of a stripped muscle. Label the parts A, B, C, D, E and F.

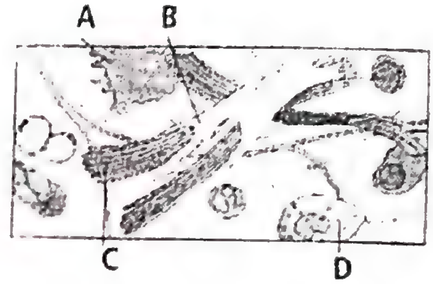


(1) A - Sarcoplasm, B- Nucleus, C - Sarcolemma, D - Myofibril, E - Dark band, F - light band
(2) A - Sarcoplasm, B - Light band, C - Myofibril, D - Sarcolemma, E - Nucleus, F - Dark band
(3) A - Light band, B - Sarcoplasm, C - Myofibril, D - Sarcolemma, E - Nucleus, F - Dark band
(4) A - Sarcolemma, B - Nucleus, C - Dark band, D - Light band, E - Sarcoplasm, F - Myofibril *(Karnataka CET 2011)*

179. The non-keratinized stratified squamous epithelium is present in
(1) epidermis of skin of hand and vertebrate
(2) vagina and cervix
(3) oral cavity
(4) vagina, cervix and oral cavity
(Orissa JEE 2011)

180. People who have migrated from the planes to an area adjoining Rohtang Pass about six months back
(1) have more RBCs and their haemoglobin has a lower binding affinity to O_2
(2) are not physically fit to play games like football
(3) suffer from altitude sickness with symptoms like nausea, fatigue, etc.
(4) have the usual RBC count but their haemoglobin has very high binding affinuty to O_2 *(CBSE PMT Prelims 2012)*

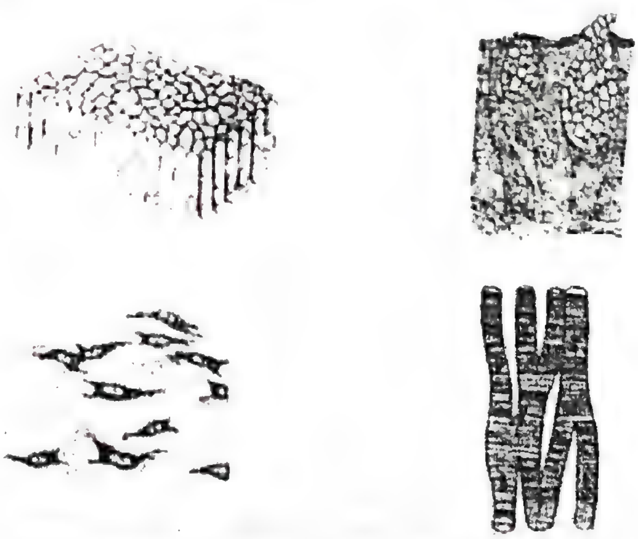
181. Given below is the diagrammatic sketch of a certain type of connective tissue. Identify the parts labelled A, B, C and D and select the right option about them



	A	B	C	D
(1)	Macrophage	Fibroblast	Collagen fibres	Mast cell
(2)	Mast cell	Macrophage	Fibroblast	Collagen fibres
(3)	Macrophage	Collagen fibres	Fibroblast	Mast cell
(4)	Mast cell	Collagen fibres	Fibroblast	Macrophage

(CBSE PMT Mains 2012)

182. The four sketches A, B, C and D given below represent four different types of animal tissues. which one of these is correctly identified in the options given along with its correct location and function ?



	Tissue	Location	Function
(1)	(B) Glandular epithelium	Intestine	Secretion
(2)	(C) Collagen fibres	Cartilage	Attach skeletal muscles to bones
(3)	(D) Smooth muscle tissue	Heart	Heart contraction
(4)	(A) Columnar epithelium	Nephron	Secretion and absorption

(CBSE PMT Main 2012)

183. The supportive skeletal structures in the human external ears and in the nose tip are examples of
(1) Ligamens (2) Areolar tissue
(3) Bone (4) Cartilage
(CBSE PMT Mains 2012)

184. The cell membranes of adjacent cells are fused at
(1) macula adherens
(2) zonula adherens
(3) zonula occludens
(4) nexus *(AMU 2012)*

185. Bone is mainly composed of
(1) iron and phosphorus
(2) sulphur and calcium
(3) calcium and phosphorus
(4) calcium and magnesium
(West Bengal JEE 2012)

186. Simple storage protein that coagulates upon heating but remains soluble in dilute salt solution is correctly examplified by
(1) globilin (2) albumin
(3) histone (4) collagen
(West Bengal JEE 2012)

*187. Choose the correctly matched pair
(1) Inner surface of bronchioles – squamous epithelium
(2) Inner lining of salivary ducts – Ciliated epithelium
(3) Moist surface of buccal cavity – Glandular epithelium
(4) Tubular parts of nephrons – Cuboidal epithelium *(AIPMT 2014)*

188. Choose the correctly matched pair
(1) Cartilage – Loose connective tissue
(2) Tendon – Specialized connective tissue
(3) Adipose tissue – Dense connective tissue
(4) Areolar tissue – Loose connective tissue *(AIPMT 2014)*

189. The function of the gap junction is to
(1) performing cementing to keep neighbouring cells together.
(2) facilitate communication between adjoining cells by connecting the cytoplasm for rapid transfer of ions, small molecules and some large molecules
(3) separate two cells from each other
(4) stop substance from leaking across a tissue *(AIPMT Retest 2015)*

190. Which type of tissue correctly matches with its location?

	Tissue	Location
(1)	Areolar tissue	Tendons
(2)	Transitional epithelium	Tip of nose
(3)	Cuboidal epithelium	lining of stomach
(4)	Smooth muscle	Wall of intestine

(AIPMT/NEET 2016)

191. Name the blood cells, whose reduction in number can cause clotting disorder, leading to excessive loss of blood from the body.
(1) Erythrocytes (2) Leucocytes
(3) Neutrophils (4) Thrombocytes
(NEET-2-2016)

192. Serum differs from blood in
(1) lacking globulins
(2) lacking albumins
(3) lacking clotting factors
(4) lacking antibodies *(NEET-2-2016)*

193. Adult human RBCs are enucleate. Which of the following statement(s) is/are most appropriate explanation for this feature?
(i) They do not need to reproduce
(ii) They are somatic cells

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*187. (a) Inner surface of bronchioles has ciliated columnar epithelium.
(b) Inner lining of salivary ducts has cuboidal epithelium
(c) Moist surface of buccal cavity has Non-keratinised stratified squamous epithelium.

(iii) They do not metabolize
(iv) All their internal space is available for oxygen transport

Options :
(1) Only (iv) (2) Only (i)
(3) (i), (iii) and (iv) (4) (ii) and (iii)
(NEET 2017)

194. Myelin sheath is produced by
(1) Schwann cells and Oligodendrocytes
(2) Astrocytes and Schwann cells
(3) Oligodendrocytes and Osteoclasts
(4) Osteoclasts and Astrocytes
(NEET 2017)

ANSWERS

1. (1)	2. (2)	3. (2)	4. (3)	5. (2)	6. (3)	7. (3)	8. (4)	9. (1)	10. (1)
11. (4)	12. (3)	13. (2)	14. (2)	15. (1)	16. (1)	17. (3)	18. (4)	19. (1)	20. (3)
21. (1)	22. (2)	23. (4)	24. (2)	25. (4)	26. (4)	27. (1)	28. (4)	29. (3)	30. (1)
31. (1)	32. (1)	33. (3)	34. (2)	35. (2)	36. (1)	37. (4)	38. (3)	39. (1)	40. (2)
41. (4)	42. (3)	43. (1)	44. (3)	45. (1)	46. (4)	47. (3)	48. (4)	49. (2)	50. (4)
51. (4)	52. (4)	53. (2)	54. (4)	55. (1)	56. (4)	57. (1)	58. (3)	59. (1)	60. (1)
61. (2)	62. (4)	63. (3)	64. (2)	65. (1)	66. (2)	67. (2)	68. (4)	69. (3)	70. (2)
71. (1)	72. (3)	73. (3)	74. (3)	75. (3)	76. (3)	77. (1)	78. (1)	79. (1)	80. (2)
81. (4)	82. (1)	83. (2)	84. (4)	85. (2)	86. (2)	87. (4)	88. (3)	89. (4)	90. (3)
91. (1)	92. (3)	93. (2)	94. (4)	95. (3)	96. (4)	97. (4)	98. (2)	99. (2)	100. (1)
101. (2)	102. (2)	103. (2)	104. (4)	105. (2)	106. (3)	107. (1)	108. (3)	109. (2)	110. (1)
111. (2)	112. (3)	113. (3)	114. (2)	115. (2)	116. (3)	117. (1)	118. (3)	119. (2)	120. (2)
121. (4)	122. (2)	123. (4)	124. (4)	125. (3)	126. (4)	127. (2)	128. (4)	129. (3)	130. (1)
131. (1)	132. (1)	133. (2)	134. (2)	135. (3)	136. (1)	137. (1)	138. (4)	139. (1)	140. (2)
141. (3)	142. (3)	143. (3)	144. (3)	145. (4)	146. (3)	147. (4)	148. (2)	149. (1)	150. (2)
151. (1)	152. (2)	153. (3)	154. (1)	155. (4)	156. (1)	157. (1)	158. (3)	159. (3)	160. (4)
161. (3)	162. (2)	163. (3)	164. (3)	165. (1)	166. (3)	167. (1)	168. (3)	169. (4)	170. (2)
171. (1)	172. (1)	173. (1)	174. (1)	175. (4)	176. (1)	177. (3)	178. (3)	179. (4)	180. (1)
181. (1)	182. (1)	183. (4)	184. (3)	185. (3)	186. (2)	187. (4)	188. (4)	189. (2)	190. (4)
191. (4)	192. (3)	193. (1)	194. (1)						

Chapter

7A Structural Organisation in Animals — Morphology and Anatomy of Animals

THEORY–a quick rundown

PHERETIMA (Earthworm)

Pheretima belongs to phylum **Annelida**, class **oligochaeta**. Prof. K.N. Bahl of Lucknow University, had written a memoir in 1926 on *Pheretima posthuma*. Common Indian earthworms are *Pheretima* and *Lumbricus**.

Earthworm is found in wet soil containing rich organic matter. It is omnivorous, fossorial, nocturnal, hermaphrodite and protandrous. Earthworm possesses a great power of regeneration.

Morphology (External Characters)

Earthworm is brown or clay-coloured due to the pigment **porphyrin**. Numerous granules of porphyrin pigment are found in the circular muscle layer of body wall. Porphyrin protects the body from the injurious effects of bright light. Body shows **metameric segmentation**. The number of segments of earthworm is about 100–120 and the length is about 150 mm. The first segment is called **peristomium** (buccal segment). Fleshy lobe-fold overhanging the mouth is **prostomium.** Prostomium is sensory in function. The **clitellum** (= **cingulum**) is a prominent circular band of glandular nature, which is found from the 14th to 16th segments. On the basis of the clitellum, the body of earthworm is divisible into **preclitellar region** (1–13 segments), **clitellar region** (14 to 16 segments) and **postclitellar region** (17 to last segment). **Setae** (= **chaetae**) are chitinous structures present in the body wall except the first, the last and clitellar segments. Setae are 'S' shaped and are 80 to 120 per segment. In *Pheretima* the setae are arranged in a ring in each segment. This type of arrangement is called **perichaetine**. In *Lumbricus*, the setae occur in two pairs on either side of the segment. This type of arrangement is called **lumbricine**. The setae help in the locomotion. They also keep the two copulating worms together by penetration into each other's body.

Following apertures are found on the body surface. (i) **Mouth** is present in the peristomium. (ii) **Anus** is found in the last or anal segment (= **pygidium**). (iii) **Female genital aperture** lies on the ventral surface of the 14th segment. (iv) **Male genital apertures** are a pair of openings lying on the ventral side of the 18th segment. (v) **Apertures of accessory glands** are present on two pairs of **genital papillae**. Genital papillae are found on the ventral surface of the 17th and 19th segments. (vi) **Spermathecal apertures** are four pairs lying in the intersegmental grooves of the segments 5/6,

**Lumbricus* is usually considered European earthworm but in NCERT Book it is written under Indian earthworms.

6/7, 7/8 and 8/9 on each side. (vii) **Nephridiopores** are numerous present all over the body except the first two segments. These are openings of integumentary nephridia. (viii) **Dorsal pores** lie on the mid-dorsal line in the intersegmental grooves, behind the 12th segment. The first dorsal pore is situated in between 12th and 13th grooves. Other dorsal pores lie in each of the succeeding intersegmental grooves except the last. Coelomic fluid oozes out through dorsal pores to keep the body surface moist.

Pores in the body wall concerned with reproduction are 11 (8 spermathecal pores, 1 female genital aperture and 2 male genital apertures).

Anatomy

Body Wall. It consists of the *cuticle, epidermis, muscular layer* and the *parietal* peritoneum. The colour appears brown due to the presence of **porphyrin** pigment in its body wall. Porphyrin protects body from harmful effects of sun light.

Coelom is the space between the body wall and alimentary canal lined externally by the **parietal peritoneum** and internally by the **visceral peritoneum**. It is filled with the coelomic fluid. It is formed by the splitting of the mesoderm of the embryo, therefore, it is **schizocoelic** in origin.

Coelomic fluid contains following types of corpuscles: (i) **Phagocytes** (ii) **Leucocytes** (iii) **Chloragogen cells or yellow cells** are excretory in function. (iv) **Mucocytes** (v) **Eleocytes** are formed by mitosis of the yellow cells of the visceral peritoneum. They contain glycogen and fat and distribute their food to various tissues. The coelomic fluid serves a **hydrostatic skeleton** during locomotion.

Lymph glands are white fluffy bodies which are found arranged on either side of the dorsal blood vessel from 26th segment and extend to the successive segments. These glands are believed to produce the phagocytes of the coelomic fluid.

Digestive System consists of alimentary canal and digestive glands.

Alimentary canal : (i) **Mouth** is situated in the peristomium which is overhung by the prostomium. (ii) **Buccal cavity** extends upto the middle of the 3rd segment. (iii) **Pharynx** extends upto the fourth segment. The pharynx is an effective organ for digestion of food. On the roof of the pharynx a muscular, glandular and vascular **pharyngeal gland** or **mass** is present. (iv) **Oesophagus** (5–7 segments) is a small narrow tube. (v) **Gizzard** is muscular (8 –9 segments) which grinds the food with the help of thick muscles and cuticle. (vi) **Stomach** (9–14 segments). The wall of stomach of earthworm contains **'calciferous glands'**. These glands secrete calcium and **carbonate ions** from food. Thus these glands help in excretion by removing excess of calcium and carbonate ions from food. The glandular cells of stomach secrete a proteolytic enzyme. Calciferous glands of the stomach neutralise the humic acid present in humus. (vii) **Intestine** starts from 15th segment to the last segment. The intestine can be distinguished into three regions. (a) **Pretyphlosolar region** extends from 15th to the 26th segment. In 26th segment, the intestine gives off a pair of short outgrowths, the **intestinal caecae** which extend forwards through 3 or 4 segments. The internal epithelium of the intestinal caecae is glandular. (b) **Typhlosolar region** is between 26-35 segments. In this region, the mid-dorsal wall of the intestine is thrown into a longitudinal fold which is known as **typhlosole**. The typhlosole increases the absorptive surface of the intestine. (c) **Post-typhlosolar region** lies between 35 to last segment. It mainly stores the faecal matter and opens to the exterior through the **anus**.

Digestive Glands. (i) **Pharyangeal gland** or **mass**. It is vascular mass situated at the roof of the pharynx. Its glandular cells are known as **chromophil cells** which secrete a fluid, the **saliva** which is passed on to the lumen of the pharynx. Saliva contains *mucus* (a lubricating agent) and a proteolytic enzyme. (ii) **Gastric epithelium** of the stomach secretes a gastric fluid which contains

proteolytic enzyme. (iii) **Intestinal epithelium** secretes an intestinal fluid which contains proteolytic, amylolytic and lipolytic enzymes. (iv) **Intestinal caecae** secrete a digestive fluid which contains amylolytic type of enzyme which is transferred to the lumen of the intestine.

The undigested food matter along with the soil is passed out through anus in the form of little heaps or pellets, the **"worm castings"**.

Blood Vascular System

Blood vascular system of earthworm is **closed type** as the blood flows in the closed blood vessels.

Blood. A coloured respiratory pigment, the **haemoglobin** is present in the plasma which gives red colour to the blood. Only one type of blood corpuscles, the **leucocytes** are present in the blood of earthworm. The leucocytes kill the harmful germs which may enter the body of the earthworm.

Blood Vessels. Following are the prominent blood vessels found in earthworm.

1. **Dorsal blood vessel.** The blood flows in this vessel from behind to forward by the rhythmic contraction (peristalsis). The dorsal blood vessel has valves which prevent the backward flow of blood.
2. **Ventral blood vessel.** It does not have any valves and flow of the blood is from the anterior to the posterior end of the body. Behind the 13th segment it gives off the **ventro-intestinal vessels** which supply blood to the intestine.
3. **Sub-neural blood vessel.** It runs from the posterior end of the body upto the fourteenth segment infront.
4. **Lateral oesophageal vessels.** It is a pair of vessels lying one on either side of alimentary canal in the first fourteen segments. Both the lateral oesophageal vessels unite to form the sub-neural vessel in the 14th segment.
5. **Supra-oesophageal blood vessel.** It is a single vessel which lies between the 9th and the 13th segments.

Hearts and anterior loops. There are present four pairs of tubular hearts. These hearts are enlarged, thick walled pulsatile and provided with valves. The anterior two pairs, known as **lateral hearts** lie in the 7th and 9th segments and connect the dorsal blood vessel with the ventral blood vessel. They receive blood from the dorsal vessel and convey it to the ventral vessel. The posterior two pairs are called **latero-oesophageal** hearts and are situated in the 12th and 13th segments. The latero-oesophageal hearts apart from connecting the dorsal and ventral blood vessels are also joined with the supra oesophageal blood vessel. Latero-oesophageal hearts carry blood from the dorsal vessel and the supra oesophageal vessel to the ventral blood vessel.

Two pairs of loop like vessels, the anterior **loops** are present in the 10th and 11th segments. These vessels connect the supra-oesophageal vessel to the lateral-oesophageal vessels. They have no valves and carry blood from the lateral oesophageal vessels to the supra oesophageal vessel.

Blood glands. These are situated in the 4th, 5th and 6th segments above the pharyngeal gland. They are considered to produce blood cells and haemoglobin. Blood glands of earthworm are analogous to red bone marrow of vertebrates.

The special respiratory organs are lacking in earthworm. The gaseous exchange takes place through the body wall (skin).

Excretory System. The main excretory organs in earthworm are **nephridia** (sing. nephridium). Nephridia of earthworm are ectodermal in origin which are analogous to vertebrate kidney. The nephridia occur in all the segments of earthworm except in the first two segments.

Three types of nephridia are found in the earthworm according to their location.

1. **Septal nephridia.** They are present on both the sides of intersegmental septa of segments 15 to the last that open into the intestine. Since the septal nephridia discharge their excretory products into the lumen of the alimentary canal/enteron, they are called **enteronephric nephridia.**

2. **Pharyngeal nephridia.** They occur in three pairs of bunches in the 4th, 5th, and 6th, segments lying on each side of the alimentary canal in these segments. Each bunch consists of a large number of nephridia. There are three pairs of ducts which run forwards. The ducts of the nephridia (carrying excretory products) of the sixth segment open into the buccal cavity while the ducts from the nephridial bunches of the fourth and fifth segments open into the pharynx. Thus like septal nephridia, the pharyngeal nephridia are also **enteronephric**. Enteronephric condition is an adaptation for the conservation of water which is absorbed by the inner lining of the alimentary canal.

3. **Integumentary nephridia.** They are found attached to the inner surface of the body wall of the segment 3 to the last clitellar region which has more integumentary nephridia hence called the "forest of nephridia". They are the smallest of the three types of nephridia. These nephridia discharge. their contents directly to the outside hence they are called **ectonephric (exonephric) nephridia.** They help the earthworm in keeping the skin moist for cutaneous respiration.

Nephridia collect excess fluid from coelomic chamber.

Chloragogen cells (yellow cells). These cells are excretory in function. They also store glycogen and fat. Thus these cells are **analogous** to the liver of vertebrates.

Earthworm is both **ammonotelic** and **ureotelic.**

Nervous System is divided into *central nervous system, peripheral nervous system* and *autonomic nervous system.*

1. **Central nervous system.** It consists of a nerve ring and ventral nerve cord.

2. **Peripheral nervous system.** The nerves which arise from the central nervous system constitute the peripheral nervous system.

3. **Autonomic nervous system.** It consists of an extensive **nerve plexus** situated beneath the epidermis, within the muscles of the body wall and on the alimentary canal. These plexuses are connected with the peripharyngeal connectives.

Receptors or Sense organs. (1) **Tactile receptors** are distributed more or less throughout the epidermis of the body wall. They are sensitive to touch. (2) **Chemoreceptors (Taste receptors)** are present in the epithelium of the buccal cavity. These receptors are the organs of *taste* plus *smell* and are, therefore, called as **chemoreceptors**. (3) **Photoreceptors** are abundant in the epidermis of the prostomium, first and second segments, while in other segments they are present in lesser numbers. They are not found on the ventral surface. These receptors detect the intesity of light. It is important to note that earthworm does not have eyes.

Reproductive System. Earthworms are **monoecious** or **hermaphrodite,** *i.e.*, both male and female reproductive organs are present in the same individual. But self-fertilization does not occur as the testes mature earlier than the ovaries. Such a condition is known as **protandry** and the animal is called **protandrous**. The self-fertilization is also not possible in this animal because of the relative position of the openings of male and female reproductive organs. The copulation occurs and **cross fertilization** takes place in the **cocoon**. After about 3 weeks each cocoon produces 2 to 20 baby worms with an average of four. Development is direct, *i.e.*, without larval stage.

Male Reproductive Organs. (1) **Testis sacs.** The two pairs of *testis sacs* are situated in the tenth and eleventh segments. (2) **Testes.** Two pairs of testes are present. Each testis arises from anterior wall of each testis sac. (3) **Seminal vesicles.** There are present two pairs of seminal vesicles which store spermatozoa. One pair lies in the testis sacs of the 11th segment. The other pair of seminal vesicles lies in the 12th segment. (4) **Spermiducal funnels.** There are two pairs of spermiducal

funnels. Each funnel leads into a fine tube, the vas deferens. (5) **Vasa deferentia**. There are present two pairs of vasa deferentia. In the 18th segment both the vasa deferentia of each side are joined to the prostate duct from the prostate gland. These three ducts (two vasa deferentia and one prostate duct) of each side are enclosed in a common thick muscular sheath, called the common **prostate and spermatic duct**. However, the three tubes are internally distinct and open to the outside separately into male genital aperture by three distinct apertures on the ventrolateral side. (6) **Prostate glands**. A pair of large prostate glands are present in earthworm. These glands extend from the segments 17 to 19. They produce a prostatic secretion which is transferred to outside on the ventral side near the opening of the vasa deferentia. The secretion perhaps serves as a medium for transfer of sperms. (7) **Accessory glands**. These are two pairs situated internally in 17th and 19th segments. Each accessory gland opens outside ventrolaterally by several ductules on each genital papilla. The secretion of these glands is supposed to help in keeping the two worms close together during copulation.

Female Reproductive Organs. (1) **Ovaries**. There is a pair of ovaries attached to the septum present between 12th and 13th segments. Ovaries are larger than testes. They produce ova. (2) **Oviducts**. Ovarian funnels (2) are present below the ovaries which continue into oviucts. There are two oviducts which open to outside by a **female genital pore** on mid-ventral side of the 14th segment. (3) **Spermathecae**. There are present four pairs of spermathecae which lie in the 6th – 9th segments. They store the sperms received from another earthworm during copulation.

Interaction with Mankind. Earthworms continuously bring the lower soil on the surface, and deposit it there. Thus, they plough the land, and share the work of the farmers. The large soil particles are ground up into finer ones by the gizzard.

Worm castings of the earthworms are of manurial value. The process of increasing fertility of soil by earthworm is called **vermicomposting**. The natural life-span of earthworms is of $3\frac{1}{2}$ to $10\frac{1}{2}$ years.

PERIPLANETA (Cockroach)

Cockroach belongs to the phylum **Arthropoda** class **Insecta** and order **dictyoptera**. Two kinds of cockroaches are usually found in India *viz.*, *Periplaneta americana* and *Blatta orientalis*. *Periplaneta americana* is reddish brown in colour.

Cockroaches are found in warm, dark and damp places. Commonly inhabit kitchens, restaurants, store houses, godowns, railway wagons, ships, etc. and numerous in underground drains. They are **nocturnal, omnivorous** and **cursorial** insects. They are unisexual and show **sexual dimorphism.** They are **oviparous**. The young cockroaches, called the **nymphs**, resemble the adults in most of the characters, but are smaller in size, pale in colour, devoid of wings and are not sexually mature. Nymphs undergo **moulting** or **ecdysis**, in which the casting of older skin takes place; gradually change into adults.

Morphology

Exoskeleton. The body of cockroach is externally covered by hard brown chitinous plates, the **sclerites**. The sclerites are joined with one another by thin flexible, soft **articular** or **arthrodial membranes.**

Body Divisions. The body of cockroach is distinctly divided into three regions, *viz.*, head, thorax and abdomen. A very small neck is also present in between the head and thorax.

1. **Head.** The proximal semi-circular broader end of the head is directed upwards, while the distal narrow, mouth bearing end is directed downwards. This type of head is called **hypognathus**.

Head capsule. In the adult, all the sclerites of the head are fused to form a **head capsule**. The top of the head capsule is known as **vertex**. The latter is divided by 'λ' shaped **epicranial suture** into two **epicranial plates**.

Sense organs. Two large **compound eyes** lie on the top of the head. They are formed by a large number of visual elements, the **ommatidia**. Just inner to each eye, a long, many jointed **antenna** arises from the **antennal socket**. Each antenna consists of three parts : (i) **Scape**-basal part, (ii) **Pedicel** is a short and middle portion, (iii) **Flagellum** is long filamentous, many jointed.

The antennae are movable and possess tactile sensory bristles. With the help of antennae, the cockroaches can detect the presence of food and the object in front. A small rounded pale-coloured area, the **fenestra** or **ocellar spot** is situated just towards the inner and upper side of each antennal socket. They represent the undeveloped simple eyes.

Mouth parts. The **biting and chewing type** of mouth parts of cockroach consist of a *labrum*, two *mandibles*, two *maxillae, a labium* and a *hypopharynx*.

(i) **Labrum.** It is also called as upper lip. A thin plate, the **epipharynx**, is fused to the inner surface of the labrum. The epipharynx bears the organs of taste. (ii) **Mandibles**. Inner margin of each mandible bears **teeth**, while on its upper inner edge, a soft lobe, the **prostheca**, is present. When both the mandibles work simultaneously in a horizontal plane, the food matter is cut and masticated into fine and smaller pieces. (iii) **Maxillae**. Each maxilla consists of three parts : (a) **Protopodite**. It is a basal portion and made up of two parts : the proximal **cardo** and the distal **stipes**. (b) **Endopodite**. It consists of two parts : outer broad, hood-like **galea** and an inner, hard plate-like **lacinia** with numerous strong sensory bristles at its inner surface. (c) **Exopodite**. It consists of a small basal sclerite, the **palpifer** and a five jointed **maxillary palp** with tactile sensory bristles. With the help of lacinia, it holds the food and gives it to the mandibles for mastication. Maxillae are also used for cleaning the antennae and the first pair of legs. (iv) **Labium**. It comprises the following parts. (a) **Protopodite**. It consists of a proximal large part, the **sub-mentum**, the middle small **mentum** and the distal **pre-mentum**. The sub-mentum and mentum are together called as **post-mentum**, which probably represents the fused cardos, while pre-mentum is perhaps the fused portion of two stipes. (b) **Endopodite**. Partially fused; represented by the **ligula** whose each half consists of an inner **glossa** and an outer **paraglossa**, which correspond to the lacinia and galea of the first pair of maxilla. (c) **Exopodite**. It consists of two parts. A small sclerite, the **palpiger**, and a three jointed **labial palp**, bearing sensory bristles. It corresponds to the maxillary palp of the first maxilla. (v) **Hypopharynx**. An **efferent salivary duct** carrying the saliva from the salivary glands opens near the base of the hypopharynx. Hypopharynx directs the saliva towards the food.

Neck or Cervicum. The neck is a movable short, soft and thin region, which connects the head with the thorax. It is supported by two dorsal and two ventral chitinous plates, the **cervical sclerites**.

2. **Thorax.** It consists of three segments. The anterior *prothorax*, middle *mesothorax* and posterior *metathorax*.

(i) **Thoracic Sclerites.** Each thoracic segment is enclosed by four chitinous skeletal sclerites. A dorsal **tergum**, a ventral **sternum** and two lateral **pleura (sing. pleuron)**. The tergum of the prothorax is also called **pronotum**, which is the largest sclerite and projects forwards to cover the neck.

(ii) **Thoracic Appendages.** The thorax bears three pairs of legs and two pairs of wings. (a) **Legs**. Each thoracic segment bears a pair of walking legs. According to their position, they are named as **pro-legs, meso-legs** and **meta-legs**. Each leg is composed of five **podomeres** : **coxa**,

trochanter, femur, tibia, and tarsus. It is composed of five **tarsomeres**. The terminal tarsomere is known as **pretarsus**, which bears two sharp curved **claws** and a soft hairy pad, the **pulvillus (arolium)**, in between the two claws. Each tarsomere possesses a soft adhesive pad, the **plantula** on its lower side. The claws and pads help the cockroach in grasping the substratum firmly. (b) **Wings**. In fact, the wings are the membranous outgrowths of the body wall, supported by a network of ridges, the **nervures**. During early stages nervures are filled with blood, but later on they are filled with air. **Mesothoracic Wings** (Fore wings) are not used for flight, but cover and protect the metathoracic wings. They are also called **wing-covers** or **tegmina**. **Metathoracic Wings** (Hind Wings) are used for flight, but in the resting position, lie folded below the tegmina.

(iii) **Thoracic spiracles.** There are present two pairs of thoracic spiracles. Fresh air enters and foul air is expelled out through spiracles.

3. **Abdomen.** A pair of **stink glands** is present in 5th and 6th terga. The abdomen in both males and females consists of 10 segments. In females the 7th sternum in boat shaped and together with the 8th and 9th sterna forms a **brood** or **genital pouch** whose anterior part contains female gonopore, spermathecal pores and collateral glands. In males, genital pouch or chamber lies at the hind end of abdomen bounded dorsally by 9th and 10th terga and ventrally by the 9th sternum. It has dorsal anus, ventral male genital pore and gonapophysis. Male cockroach has a pair of short thread like **anal styles** which are absent in females. Both in male and female the 10th segment bears a pair of jointed filamentous **anal cerci.**

Periplaneta americana is reddish brown in colour. It is a native of America. Both male and female have well developed wings covering the entire abdomen. *Blatta orientalis* is dark brown in colour. It is a native of Asia. The wings of the males are shorter than the body while the wings of females are rudimentary.

Anatomy

Endoskeleton. At some places, certain processes (projections) of exoskeleton extend into the body and form **endoskeletal elements.** These provide attachment to the muscles and hence called **apodemes** : (i) A tent-like plate, called **tentorium,** forms the endoskeleton of head. (ii) In the thorax, separate processes of sternites of the three segments form endoskeleton. (iii) Abdomen of cockroach does not have endoskeletal elements.

Body Wall. (i) **Cuticle.** It forms the outermost layer of the body wall secreted by the epidermis and consists of three sub-layers. (a) **Epicuticle.** Outer, thin and waxy layer which is usually impermeable to water. Chitin is absent in epicuticle. (b) **Exocuticle.** The middle laminated, tough, chitinous pigmented thinner layer. (c) **Endocuticle.** Thick innermost layer formed of soft laminated chitin.

The cuticle forms some immovable tactile bristles or **spines.**

(ii) **Epidermis.** It consists of single layered columnar cells. Certain cells of the epidermis are modified into **trichogen cells** which secrete movable bristles. **Tormogen cells** secrete membranes around the bristles. **Dermal gland** cells secrete waxy substance which is spread over the cuticle and gives obnoxious smell. **Oenocytes** produce materials for the formation of epicuticle and also influence moulting **(ecdysis).**

(iii) **Basement membrane.** It lies beneath the epidermis. It is composed of flattened cells.

Body Cavity. True coelom is found during embryonic development. In adults, original coelom is present around the gonads. It is filled with blood and, therefore, called **haemocoel**. The haemocoel is divided by two horizontal perforated partitions or **diaphragms** into three spaces, the **pericardial, perivisceral** and **perineural sinuses.**

Digestive System

Alimentary Canal. The fore and hind-guts are formed by ectoderm and are lined by the cuticle internally, while the mid-gut is development from endoderm of the embryo and not lined by the cuticle.

1. **Stomodaeum or fore-gut.** It comprises the pre-oral cavity, mouth, pharynx, oesophagus, crop and gizzard. The gizzard has strong circular muscles and six teeth for grinding the food.

2. **Mesenteron or mid-gut.** It is a thin walled somewhat coiled tube with almost uniform thickness. It is the only part of the alimentary canal which is not lined by the cuticle. Main digestion and absorption of food is carried out here. A **peritrophic membrane** is formed around the food in the mid gut. This membrane is permeable to digestive enzymes and digested foods. From the junction of mid-gut and gizzard arises 6 to 8 finger-like structures called the **hepatic or gastric caecae**. The junction of mid-gut and hind-gut is marked by the presence of 100-150 yellow fine thread-like excretory structures, the **Malpighian tubules**. There is present a **stomodaeal valve** between gizzard and mesenteron.

3. **Proctodaeum or Hind-gut.** It is ectodermal in origin. It comprises the ileum, colon, rectum and anus. **Rectum** has six **rectal papillae** to absorb maximum water from undigested food.

Digestive Glands. (i) **Salivary glands.** Paired glands. The secretion is known as **saliva** which contains **amylase, maltase, invertase** and **lactase** enzymes. (ii) **Hepatic caecae** secrete digestive secretion containing amylolytic, proteolytic and lipolytic types of enzymes. (iii) **Mid-gut lining** secretes a digestive secretion containing proteolytic, amylolytic and lipolytic enzymes.

The food of cockroach consists of almost all types of organic matters, *i.e.*, paper, bread, cloth, vegetables, meat, etc. It also eats dead bodies of its fellows and other insects. It even feeds upon its fellow cockroaches (**cannibalism**). Cockroaches prefer food containing more of starch and sugar.

Blood Vascular System

The blood vascular system of cockroach is of **open type**. This system comprises the blood, haemocoel, heart, small contractile vesicle–like accessory hearts, anterior aorta, etc.

1. **Blood or haemolymph.** Composed of **corpuscles** and a colourless fluid, the **plasma**. The corpuscles are somewhat amoeboid shaped and are of two types : **proleucocytes** and **phagocytes**.The blood has high concentration of dissolved organic phosphates, uric acid and **trachaelose**—a characteristic of insects and a non-reducing sugar agent. Another important feature of the blood is that it does not contain any respiratory pigment and, therefore, plays no role in respiration.

2. **Haemocoel.** The body cavity of the cockroach is filled with blood or haemolymph and that is why it is referred to as *haemocoel*. In the thoracic and abdominal regions the haemocoel is divided by two horizontal partitions, the **diaphragms** into three large spaces. These blood filled spaces are : (i) **Pericardial sinus** present on the dorsal side and encloses the heart ; (ii) **Perivisceral sinus** is the largest and encloses most of the viscera concerned with the systems of digestion, respiration, excretion, reproduction, etc. (iii) **Perineural sinus** lies on the ventral side above the sterna and encloses nerve cord.

Some blood-filled spaces are also found in the head which are known as **head sinuses.**

3. **Heart.** Lies mid-dorsally below the terga in the pericardial sinus. It consists of thirteen contractile chambers. The first chamber of the heart forms a single narrow tubular **anterior aorta** leading into the head sinuses. At the posterior end of each chamber, a pair of apertures, the **ostia**, are present laterally. The heart receives blood from the pericardial sinus through ostia. Ostia are guarded by **auricular valves** to check the flow of blood from the heart to the paericardial sinus. All the chambers of the heart are inter-connected and their openings are guarded by the **ventricular valves.**

to allow the blood flow anteriorly only. The last chamber is closed posteriorly. Heart of cockroach is **neurogenic.**

There are present twelve pairs of fan shaped and triangular **alary muscles**; their narrow ends are inserted into terga, while their broader ends are attached to dorsal diaphragm. The contractile alary muscles play a significant role in the blood flow from the heart to other haemocoelic spaces in blood circulation.

Respiratory System

Being terrestrial cockroach utilizes atmospheric oxygen for respiration through definite respiratory organs. The atmospheric air directly comes in contact with the various organs of the body and, therefore, the blood is not used for respiration.

1. **Spiracles.** There are ten pairs of slit-like openings, the **spiracles.** The first two pairs are lying in thorax and the remaining eight pairs are present in the abdomen. An annular sclerite called **peritreme,** surrounds the spiracle.

2. **Tracheae.** The tracheae are ectodermal tubes formed by the invaginations of the integument. There are present three longitudinal tracheal trunks on each side of the abdominal cavity. These are the dorsal, ventral and lateral trunks. The tracheal wall consists of an outer delicate single layered syncytial epithelium and inner cuticle. The cuticle forms cuticular thickening to prevent the trachea from collapsing.

3. **Tracheoles.** Ultimately, the trachea divides into fine branches known as **tracheoles.** They are devoid of cuticular thickenings. They terminate in the tissues and contain a tissue fluid at the distal end which plays a significant role during the diffusion of the gases.

Excretory System

1. **Malpighian Tubules.** These are attached at the junction of mid and hind-gut . The distal closed end of each tubule floats freely in the blood of perivisceral sinus and the proximal end opens into the hindgut. These tubules extract metabolic wastes like potassium and sodium urate, water and carbon dioxide from the blood. Uric acid is carried to the alimentary canal of the insect and is finally passed out through anus. Elimination of uric acid as excretory product is called **uricotelic excretion.**

2. **Fat Body.** Fat body has trophocytes, mycetocytes, oenocytes and urate cells.

3. **Nephrocytes.** Large colourless ovoid binucleate cells attached to the dorsal diaphragm in the body cavity. They are arranged on each side of the heart and hence they are also called **pericardial cells.** The function of these cells is not clearly understood. They may be excretory in function.

Cuticle. The nitrogenous wastes are deposited beneath the cuticle and are eliminated from the body during moulting (ecdysis).

Nervous System

1. **Central Nervous System.** Consists of the **brain** (supraoesophageal ganglion), **circumoesophageal connectives, suboesophageal ganglion** and **ventral nerve cord.** There are present prothoracic, mesothoracic and metathoracic ganglia in respective thoracic segments and six abdominal ganglia. 5th abdominal segment does not have a ganglion.

2. **Peripheral Nervous System.** It comprises various nerves originating from the central nervous system.

3. **Sympathetic Nervous System.** Comprises : (i) **Frontal ganglion.** It lies on the dorsal wall of the pharynx in front of the brain. (ii) **Occipital ganglion.** Three nerves arise from the occipital ganglion. The two lateral ones are called **occipital nerves;** each runs to the corpus cardiacum

(endocrine gland) of its side. The median one, the recurrent nerve passes posteriorly on the oesophagus. (iii) **Ingluvial ganglion.** It is present on the crop. A pair of lateral ingluvial nerves arise from the ingluvial ganglion (= visceral ganglion) posteriorly over the crop.

Endocrine System

It consists of intercerebral gland cells, corpora cardiaca, corpora allata and prothoracic glands.

1. **Inter-Cerebral Gland Cells.** They secrete **brain hormone** which activates the prothoracic glands to secrete their hormone.

2. **Corpora Cardiaca.** They secrete a **growth hormone.**

3. **Corpora Allata.** They secrete a **juvenile hormone** (= neotinin), which retains the nymphal characters and checks the appearance of adult characters. When the juvenile hormone is absent, it permits the appearance of the adult characters. It is important to note that corpora allata again becomes active in adult cockroach and secretes a **gonadotropic hormone,** which regulates the development and functioning of the reproductive organs.

4. **Prothoracic Glands.** They secrete a hormone, the **ecdyson** to control **ecdysis** of the nymph. These glands degenerate after metamorphosis.

Sense Organs

1. **Photoreceptors (Compound eyes).** The two compound eyes occupy a large area on each side of the head. Each eye is black, kidney shaped and bears about 2000 facets externally. Each facet actually represents a visual element, the **ommatidium.** Thus, each compound eye contains about 2000 ommatidia. The image is compound and is made up of large number of separate immature images each of which is contributed by single ommatidium. Such an image is known as **mosaic image.**

2. **Sensillae.** A sensilla consists of a bipolar **sensory cell,** a large **trichogen** cell and a smaller **tormogen cell.** Sensillae are of the following types (i) **Tactile Sensillae.** They occur all over the body but are more abundant on the antennae, tibiae of legs and anal cerci. They respond to touch. (ii) **Gustatory Sensillae.** They occur on the tips of the maxillary and labial palps and on the epipharynx. These sensillae are for taste. (iii) **Olfactory Sensillae.** They are present on the antennae and maxillary and labial palps. They are meant for smell. (iv) **Auditory Sensillae.** These sensillae are for hearing and are present on the anal cerci. (v) **Thermoreceptor Sensillae.** They are present on the Ist, 2nd and 3rd segments of tarsus of legs.

Reproductive System

The cockroaches are **dioecious** (unisexual) animals. They exhibit sexual dimorphism, *i.e.*, male and female individuals can be distinguished externally. The female cockroach bears broad abdomen, brood pouch, but lacks anal styles, as present in the males.

Male Reproductive System

1. **Testes.** There are two testes which are present just beneath the 4th to 6th abdominal terga. The testes are prominent in young insects, but get reduced in adults. The sperms produced by the follicles of the testes are transferred to the vas deferens through the vasa efferentia.

2. **Vasa-deferentia.** These are two fine ducts which arise from the testes and open in the upper surface of the ejaculatory duct at the base of the mushroom-shaped utricular gland.

3. **Utricular gland (Mushroom Shaped Gland).** The junction of the vasa-deferentia and the ejaculatory duct is surrounded by a mushroom-shaped utricular gland. This gland is present in 6th–7th abdominal segments. It consists of long tubules, small tubules and seminal vesicles. The secretion of the **long tubules** forms the innermost layer of spermatophore. **Small tubules** provide

nourishment to the sperms. Spermatophore is a pear-shaped capsule, about 1.5 mm long, having a three-layered wall and containing spermatic fluid. The **seminal vesicles** store the sperms.

4. **Ejaculatory duct**. The base of the utricular gland leads into, the ejaculatory duct. The latter opens to the outside by an opening, the **male gonopore** lying close to ventral phallomere. The secretion of ejaculatory duct forms the middle layer of spermatophore. The spermatophores are passed outside through the male gonopore or male genital operture.

5. **Phallic gland (Conglobate gland).** The secretion of phallic gland forms the outer most layer of the spermatophore.

6. **Phallomeres (Male Gonapophyses).** There are three phallomeres that surround the male gonopore. (a) **The right phallomere** is mid dorsal in position, (b) **The left phallomere** and (c) **The ventral phallomere**. Right phallomere has **opposing plates, serrate lobe** and **hook**. Left phallomere consists of four parts : **titillator, pseudopenis, asperate lobe** and **accutolobus**. Ventral phallomere bears the male gonopore or male genital operture. The phallomeres are helpful in the transference of the spermatophore, from tubules female and some of them are used to open the genital pouch of the female.

Female Reproductive System

1. **Ovaries.** There are a pair of ovaries. They are embedded in the fat bodies from the 2 to 6th abdominal segments. Each ovary consists of **eight ovarioles** or **ovarian tubules**. Each ovariole has three distinguishable portions. (i) **Terminal Filament**, (ii) **Egg Tube** which can be further distinguished into the anterior **germarium** containing the germ cells and a posterior **vitellarium** in which the germ cells (ova) get matured and (iii) **Pedicel** is a short tube which receives the opening of the egg tube. Eggs are **centrolecithal**.

2. **Oviducts.** All the pedicels of the ovarioles of each ovary unite to form a short tubular and muscular structure, known as oviduct. Each oviduct receives ova from the ovarioles of its side and passes them to the next organ, the common oviduct.

3. **Common Oviduct** (also called vagina). The two oviducts run posteriorly and unite in the 7th abdominal segment to form a short wide common oviduct. The latter opens into the genital chamber by **female gonopore**.

4. **Brood pouch.** In encloses a boat shaped cavity. The front part of this cavity lies close to the gonopore and hence called the **genital chamber**, while the posterior part is called **oothecal chamber**, because during the breeding it contains ootheca, a structure which contains eggs (fertilized ova).

5. **Spermathecae.** There are a pair of spermathecae in the 6th abdominal segment with structures of unequal size which store the sperms after the copulation.

6. **Colleterial glands.** They are two very much branched tubuler glands, which are unequal in size. The left gland is large. Both the glands open independently on the dorsal side of the genital chamber. The secretion produced by these glands forms the **oothecal case** of the ootheca.

7. **Female Gonapophyses.** The six chitinous plates, surrounding the female gonopore or female segment gonopore, are termed as gonapophyses; function as **ovipositors**. The latter are used to carry eggs to the oothecal chamber.

Spermatophores (containing sperms) are carried from male cockroach to female. Sperms are released from the spermatophores and are stored in the spermathecae and later on released from the spermathecae. Eggs come from the ovarioles and fertilization takes place forming ootheca. Ootheca is a dark reddish to blackish brown capisule, about 3/8" (8 mm) long. On an everage a female produces 9–1000 thecae, each containing 14–16 eggs. The nymph grows by moulting about 13 times

to reach the adult form. The development in *Periplaneta americana* is **paurometabolous (gradual metamorphoris)**. It means life cycle includes **egg** (zygote) → **nymph** (young) → **Imago** (newly formed adult).

The nymph ressmbles the adult in its mode of life but differs in structure.

Interaction with Mankind

Cockroaches cause damage to the household materials such as clothes, purses, shoes, etc. They also eat and destroy human food such as bread, fruits, cheese, etc. Since they also live in sewage pipes and gutter holes, they carry harmful germs of diseases like diarrhoea, cholera, typhoid, tuberculosis, etc. They also produce obnoxious smell in kitchens and stores. In south American countries and in Myanmar people eat cockroaches. Many animals such as amphibians (*e.g.*, frogs, toads), lizards, birds and rodents eat cockroaches. Thus they are the part of food chain.

RANA TIGRINA (The Common Indian Frog)

The frog belongs to the phylum **Chordata**, subphylum **Vertebrata** (= craniata), group **Gnathostomata**, super class **Tetrapoda**, class **Amphibia**, order **Anura**.

Rana tigrina is the most widely distributed species in Northern India. Generally frogs are found in ponds, tanks, pools, ditches, etc. However, they may leave their aquatic habitat to come on land to hunt for their prey, which are mostly insects. Hence they are called amphibious.

Locomotion : (a) Jumping and leaping, (b) *Swimming*— Absence of neck is helpful in swimming in water and jumping on land. **Feeding**. The adult frog is **carnivorous.** Tadpole (larva) is **herbivorous**. **Croaking**. The male frog croaks louder than the females because of the presence of two **vocal sacs** situated on the posterior part of the throat in male frog which act as resonators. The croaking is a mating call to attract the female frog. **Hibernation** (Winter Sleep). During hibernation frog respires through skin (cutaneous respiration) only. **Aestivation** (Summer sleep). During this period frog takes rest and recuperates its energy. **Protective Colouration**. The frog can change its skin colour to match the colour of external environment. This capability is called **metachrosis.** It can not only avoid its enemies but can catch its prey unnoticed. **Breeding**. The male frog jumps on the back of the female frog and holds her tightly with the help of his fore-limbs. Gripping of the female by the male is also very much aided by the presence of **nuptial pads**. This sexual embrace is called the **amplexus**. Fertilization is external. During development, a fish-like tailed tadpole is produced, which respires with the help of gills and feeds upon vegetable matter.

Morphology (External Characters)

The body of frog is divisible into two parts only : the **head** and the **trunk**. *The neck and tail are not present.* **The upper eye-lid** is prominent, thick and slightly movable, while the **lower eye-lid** is vestigial and immovable. A little above the lower eye-lid, a transparent **nictitating membrane**, mistakenly referred to as the third eye-lid, is present. Just behind the eyes on each side a pigmented **tympanum** (ear covering) is present.

Betweeen the anterior borders of the eyes on the mid-dorsal line is present a small, lightly coloured, but a conspicuous patch, known as **brow spot**, below which is situated the **pineal body**, a part of brain. Brow spot is sensitive to light.

The trunk comprises **thorax** and **abdomen**. The fore-limb consists of **upper arm (brachium)**, **fore-arm (antebrachium)**, **wrist** and a **hand (manus)** bearing four **fingers**. First digit in the fore limb which is called **pollex**, is absent. The **hind-limb** consists of proximal **thigh**, **shank**, **ankle** and a **foot** (pes) bearing five **toes**. First digit in hind foot is called **hallux**. The toes are connected together

by a thin membranous **web**, which helps the animal in swimming. A medially placed **cloacal aperture** is present for the outlet of faecal matter, urine and reproductive product.

Sexual Dimorphism. The male and female frogs can be differentiated externally : The male frog possesses vocal sacs, which are most developed during the breeding season. During the breeding season an **amplexusory** or **nuptial pad** is developed on second finger of each hand of the male frog.

Anatomy

Skin (Integument). The colour of frog can be changed according to the surroundings. It consists of two layers— an outer **epidermis** and inner **dermis**.

The chromatophores are of three types : (i) **Lipophores** having red and yellow pigments. (ii) **Guanophores** containing white pigment. (iii) **Malanophores** possessing the black and brown pigments. The olive greeenish colour is due to the combined effect of these three pigments.

There are two kinds of glands in the stratum spongiosum : (i) **Mucous glands** are many in number and secrete mucus, which makes the skin moist and slippery in nature, (ii) **Poison glands** are few in number and only infrequently present in frog, but mostly present in toads. They secrete a poisonous fluid for protection. Both mucous and poison glands are formed by the stratum germinativum and invaginated below with their necks opening on the surface of the skin.

Body Cavity (Coelom). The space or cavity lined by parietal peritoneum externally and visceral peritoneum internally is known as **coelom**. The coelom of frog is divisible into. (i) an anterior small **pericardial cavity** enclosing the heart and (ii) posterior spacious **abdominal** (pleuroperitoneal) **cavity** in which the rest of the internal organs lying in the trunk are lodged.

Digestive System

Alimentary canal. The teeth are absent on the lower jaw while the upper jaw bears similar small, backwardly directed conical teeth known as **maxillary teeth**. In addition there are present two patches of **vomerine teeth** one on each vomer bone, near the internal naris. All teeth are similar and are, therefore, known as **homodont**. If the teeth are broken or worn out, they are easily replaced many times. Such teeth are called **polyphyodont**. Unlike man, the teeth of frog are not lodged in sockets but fixed by an adhesive secretion, the **cement**. Such teeth are known as **acrodont**. The teeth of frog are not masticatory. The tongue is fixed in front but its hinder end is free and bilobed. The free bilobed posterior end can be thrown out and retracted backward with a great speed after catching the prey.

Because of the absence of neck in frog, the oesophagus is only a short tube. Jejunum is absent.

Cloaca is the last part of the alimentary canal, which receives the rectum in both the sexes, but in female frog, the cloaca also receives the ureters and oviducts, while in the male the urinogenital ducts are received in addition to the rectum. The urinary bladder also opens into the cloaca. The cloaca opens out through a **cloacal aperture**.

Digestive Glands are liver, pancreas gastric glands and intestinal glands.

Respiratory System. The adult frog respires in three different manners : (1) The **cutaneous respiration** is carried out in water. During winter sleep and aestivation (summer sleep) it is the only method of respiration in frog. (2) **Buccopharyngeal respiration** occurs when the animal is on the land or partially immersed in water. During this mode of respiration, the mouth and glottis are tightly closed while the nares are kept open. (3) **Pulmonary respiration** is less frequent than the cutaneous and buccopharyngeal respiration.

Sound Producing Organ. A thin walled **laryngotracheal chamber** is the sound producing organ in the frog. It corresponds to the larynx and trachea of higher animals. Since the neck is absent in the frog, the larynx and trachea are combined to form the laryngotracheal chamber.

Blood Vascular System. It is of **closed type**. It represents **single circulation**. It means both the oxygenated and the deoxygenated blood enters the heart and get mixed in the ventricle. Blood vascular system comprises blood, heart and blood vessels.

Blood. It is mobile connective tissue consisting of blood plasma (fluid) and blood corpuscles (cells). Three types of blood corpuscles are present in the plasma, viz, **erythrocytes** (RBCs–Red blood corpuscles), **leucocytes** (WBCs — white blood corpuscles) and **thrombocytes** – **spindle cells**. RBCs are nucleated, oval and biconvex and have **haemoglobin** (respiratory pigment). WBCs are amoeboid shaped and are protective in function. Thrombocytes are spindle shaped and help in blood clotting.

Heart. The heart, is a modified blood vessel to receive and distribute the blood. The heart is situated midventrally in the thorax in between the two lungs.

In addition to two auricles and one ventricle, there are also two other associated structures, known as **sinus venosus** and **truncus arteriosus** (= conus arteriosus).

In addition to the above mentioned structures, there is present one patch of modified muscle fibres, the **sinu-auricular node** lying in the wall of sinus venosus. This node is called the **pace maker** of heart. Heart of frog is **myogenic**. It means that initiation of heart beat is from a set of specialized cardiac muscle fibres called sinu auricular node (S. A. node).

Portal Systems. There are two Portal systems— renal portal system and hepatic portal system.

Significance of Renal Portal System. The renal portal system collects the blood from the hind parts on the body from which the urea and uric acid present in the blood are first got filtered in the kidneys before the blood goes into postcaval and then to the heart. Thus, the blood going to the heart contains comparatively less impurities after passing through the renal portal system.

Significance of hepatic portal system. (a) The blood which comes from the alimentary canal contains digested food like glucose and amino acids. The excess of glucose is converted into glycogen which is stored in the liver for later use. When an individual feels deficiency of food, the glycogen is converted into glucose and is transferred to the blood stream via hepatic veins. (b) Harmful nitrogenous waste like ammonia is converted into urea which is later removed by kidneys. (c) Liver produces blood proteins which are put into blood circulation.

Lymphatic System. Lymph is like blood but it is without RBCs and thrombocytes. It is colourless. Lymph acts as "middle man". In addition to the lymph, lymphatic system comprises **lymph capillaries**, (closed at the tip), **lymph sinuses** (spaces filled with lymph) and two pairs of **lymph hearts**. The flow of lymph is from the lymph capillaries (**lacteals**) → lymph sinuses → lymph hearts → veins. Functions of lymph are described in the Chapter `Animal Tissues'.

Spleen. It is a dark, red oval structure lying near the anterior end of the rectum. It produces RBCs and WBCs in adult frog too. It stores blood hence it is called "blood bank".

Brain. The brain is covered by two membranes or **meninges** (sing. **meninx)**. The outer tough, thick membrane is **duramater**, and the inner thin, more delicate and vascular membrane is **pia-arachnoid membrane**.

Fore Brain. It comprises two olfactory lobes, two cerebral hemispheres and a diencephalon.

Mid Brain. It consists of optic lobes and crura cerebri.

Hind Brain. It comprises cerebellum and medulla oblongata.

Ventricles. The brain is hollow containing cavities, which are filled with the **cerebro-spinal fluid**

secreted by anterior and posterior-choroid plexuses. The cavities of the brain are known as **ventricles**. Each olfactory lobe encloses a ventricle termed as **rhinocoel** which leads into the ventricles of the cerebral hemisphere, the **lateral ventricles** or **paracoels** or **first** and **second ventricles**. Two lateral ventricles open into the ventricle of the diencephalon, the **diocoel** or **third ventricle** through an aperture, the **foramen of Monro**. Each optic lobe contains a cavity which is called **optocoel**. The two optocoels open into a narrow tubular cavity, the **iter** which connects the diocoel with the **myelocoel** or **fourth venticle** (a triangular ventricle of the medulla oblongata). The ventricle of the cerebellum is called the **metacoel**. The myelocoel communicates with the **central canal** of spinal cord.

Spinal Cord. It lies in the neural canal of vertebral column and extends from the medulla oblongata of the brain to almost at the end of back-bone. The spinal cord is surrounded by the same two protective membranes; the meninges, as in the brain viz., a thick outer **duramater** and a thin inner vascular **pia-arachnoid membrane.**

In frog, it is short, somewhat flattened structure which widens anteriorly and tapers towards the posterior end into the urostyle, where it is called **filum terminale**.

Cranial Nerves. In frog, the number of cranial nerves is **ten pairs.** (1) Olfactory Nerve, (2) Optic Nerve, (3) Oculomotor Nerve, (4) Trochlear (Pathetic) Nerve, (5) Trigeminal Nerve, (6) Abducens Nerve, (7) Facial Nerve (8) Auditory Nerve, (9) Glossopharyngeal Nerve and (10) Vagus Nerve.

Spinal Nerves. These nerves arise from the spinal cord and are normally nine pairs, sometimes 10th unpaired nerve is also seen. Rarely 10 pairs of spinal nerves are found. As soon as the spinal nerve comes out of the vertebral column, the origin of each nerve is covered with soft white calcarious masses, which are called **glands of Swammerdam or periganglionic glands** in which calcium is reserved.

There is a noteworthy point that the roots of seventh to tenth nerves first run inside the neural canal of the vertebral column for some distance to form a horse-tail shaped structure, the **cauda equina**. Later on these nerves come out of the neural canal.

Sympathetic Nervous System. It consists of two longitudinal **sympathetic cords**, one on either side of the vertebral column ventral to the dorsal aorta, and run forward along the outer sides of the systemic arches. On stimulation the sympathetic nerve fibres secrete a chemical **norepinephrine** (formerly called symathin) which stimulates the organs to function.

Parasympathetic Nervous System. There is no such cord or ganglia as found in the sympathetic nervous system. It consists of very small parasympathetic ganglia situated in the walls of visceral organs (viscera) and nerve fibres. These are connected with the central nervous system after travelling in some **cranial** and **spinal nerves**. On stimulation, the parasympathetic nerve fibres secrete a chemical called **acetylecholine**, whose function is just opposite to that of sympathin. The function of sympathetic and parasympathetic nervous system is **antagonistic** to each other. Autonomic nervous system is ultimately controlled by diencephalon (hypothalamus) of the brain.

Eyes. Each eye is provided with upper and lower eye lids which are actually simple folds of skin. The **upper eye lid** is thick and slightly *movable*. The **lower eye lid** is vestigial and *immovable*. The **nictitating membrane** is movable, semitransparent and can be drawn over the eye when animal is inside water where it prevents aquatic infection and also enables the frog to see under water. This membrane is retracted when the frog is on land. A **harderian gland** is present below the lower eye lid whose secretion lubricates the eye ball and nictitating membrane.

Layers of eye ball. The wall of the eye ball mainly consists of three layers :

(i) **Outer Fibrous Coat**. Two third part of this layer is opaque and is known as **sclerotic.** In frog sclerotic is *cartilaginous*. The remaining one-third of the outer layer is transparent and bulges out to form the **cornea**. The cornea is lined externally by a thin transparent membrane, the **conjunctiva.**

(ii) **Middle Vascular Coat. Choroid** lies next to outer layer which is richly supplied with blood capillaries and black pigmented cells. It forms the iris to enclose an oval aperture, the **pupil**. A vascular fold of the choroid, the **ciliary body** lies behind the iris. The **ciliary processes** arise from the ciliary body. The ciliary body is poorly developed in frog.

Just behind the iris, a transparent, crystalline and almost spherical lens is situated, which is enclosed in the delicate transparent **lens capsule**. It is held and kept in position by the fibres of the **suspensory ligament**, which extend from the lens capsule to the ciliary body. The lens divides the cavity of the eye ball into **aqueous chamber** and **vitreous chamber**. The aqueous chamber contains a transparent watery fluid, the **aqueous humour,** while the vitreous chamber contains a jelly like substance, the **vitreous humour**.

There are two **protractor lentis muscles**, one dorsal and one ventral, which extend between the cornea and the inner part of the ciliary body. They help in the slight adjustment of the object.

(iii) **Inner Nervous Coat** (= Retina). It is the innermost layer of the eye on which the image is formed. Where the optic nerve arises, that point is called **blind spot**; no image is formed at this spot because sensitive cells of retina are absent at this point. A point on the retina where sharpest image is maintained, lies more or less opposite the centre of the pupil, is called **yellow spot** or **area centralis**. This spot contains numerous cones.

Ears. The ears are hearing and balancing organs, which are situated just behind the eyes. Each ear consists of two parts : 1. Middle ear, 2. Internal ear.

1. **Middle ear.** Externally, it bears a rounded patch, the **tympanum** or **tympanic membrane**, which is tightly mounted on a cartilaginous ring, the **tympanic ring**. Inner to the tympanic membrane an air filled chamber is present which is known as **tympanic cavity** that communicates with the buccopharyngeal cavity through a narrow **Eustachian tube**. A club shaped rod like structure, partly formed of bone and partly of cartilage, the **columella auris** extends from the centre of the tympanic membrane and attaches with a plug of cartilage, the **stapes** which lies over a small oval aperture, the **fenestra ovalis** that leads into **auditory capsule**.

2. **Internal ear.** It is lodged in the bony **auditory capsule**, which is mainly formed by **pro-otic bone**, whose cavity contains a watery fluid, the **perilymph**. This capsule lodges the actual statoacoustic organ known as **membranous labyrinth.** It consists of dorsal main body, the **utriculus**, and the ventral, projecting downwards smaller part, the **sacculus**. Three **semicircular canals** (anterior vertical, posterior vertical and horizontal semicircular canals) arise from the utriculus. Each semicircular canal is enlarged at one end to give rise to small rounded **ampulla.** The anterior, vertical and horizontal canals bear the ampullae at their anterior ends while the posterior vertical canal contains an ampulla each at its posterior end.

Posterior portion of sacculus forms two small rounded outgrowths, a relatively large **lagena** and smaller **pars basilaris**. Lagena is the forerunner of the cochlear duct of higher vertebrates. Pars basilaris seems to be a part of lagena. A small similar outgrowth, the **pars neglecta** arises from utriculus. Ampullae contain sensory spots called **cristae**. Utriculus, sacculus and lagena also have sensory spots known as **maculae**. The ampullae, utriculus, sacculus, lagena and three canals are supplied by the branches of auditory nerve.

Skeletal System. There is no exoskeleton in frog. **Endoskeleton** consists of **axial skeleton** (skull, vertebral column and sternum) and **appendicular skeleton** (pectoral and pelvic girdles and bones of fore and hind limbs).

Upper jaw bears teeth, however **lower jaw** is toothless.

Skull. Since the frog's skull has two occipital condyles, it is called **dicondylic skull**.

Septomaxillary bone of olfactory capsule is the smallest bone in the skull of frog. Upper Jaw bears teeth, however **lower jaw** is toothless.

In frog jaw-suspensorium is **autostylic**, *i.e.*, lower jaw attaches to skull through quadrate.

Hyoid Apparatus. Hyoid apparatus lies in the floor of buccopharyngeal cavity and provides attachment and support to the tongue.

Vertebral Column (Backbone). Frog has total ten vertebrae including **urostyle** :

(i) First vertebra is called **atlas** and is without transverse processes. It is *smallest vertebra* and its centrum is **acoelous** (convex on both the sides). Atlas articulates with the skull.

(ii) 2nd to 7th vertebrae have same structure and are called **typical vertebrae**. The centrum is **procoelous** (concave infront and convex behind).

(iii) The centrum of **8th vertebra** is **amphicoelous** (concave on both sides).

(iv) The centrum of **9th vertebra** (also called **sacral vertebra**) is acoelous. Its transverse processes are articulated with ilium of pelvic girdle (**sacroiliac joint**).

(v) **Urostyle** is the 10th vertebra. Spinal cord in frog extends upto the anterior part of urostyle. Spinal cord passes through neural canal of the vertebrae.

Sternum (= Breast bone). Ribs are absent in frog so sternum articulates directly with the pectoral girdle. The sternum consists of four parts (i) circular cartilage **episternum** (ii) Inverted 'Y' shaped cartilage **omosternum** (iii) rod like cartilage bone **mesosternum** and (iv) circular cartilage bone **xiphisternum.**

Pectoral Girdle (= Shoulder Girdle). It is composed of two halves forming a C-shaped structure. Each half consists of **suprascapula** (a calcified cartilage), **scapula, coracoid, precoracoid, epicoracoid** and **paraglenoid cartilage. Clavicle** is a slender rod like bone. Posteriorly scapula forms a deep cup-like depression, the **glenoid cavity**. The head of humerus bone of forelimb fits into glenoid cavity. Sternum connects two halves of pectoral girdle.

Pelvic Girdle (= Hip Girdle). It is 'V' shaped. Each half is composed of **ilium, ischium** and **pubis** bones. All three bones take part in the formation of a cup-shaped cavity called **acetabulum**. The head of femur bone of hindlimb fits into acetabulum.

Bones of Forelimbs. A forelimb consists of the following bones. (i) **Humerus**. It possesses a prominent, crest-like **deltoid ridge** below the head. (ii) **Radio-ulna**. A compound bone formed by the fusion of **radius** and **ulna**. (iii) **Carpals**. These are six bones, arranged into two rows of three each. (iv) **Metacarpals**. These are five bones. (v) **Digits**. There are present four digits in fore limb. First digit (= ***pollex***) is absent in frog. Each digit consists of small bones called **phalanges**. Digital formula of fore limb is 0, 2, 2, 3, 3.

Bones of Hindlimbs. A hind limb consists of the following bones :

(i) **Femur**. It consists of head, slightly curved shaft and condyle. (ii) **Tibio-fibula**. It is a compound bone formed by the fusion of **tibia** and **fibula**. A **nutrient foramen** for anterior tibial artery is present in the middle of the shaft. *Tibio-fibula is the longest bone in frog.* (iii) **Tarsals**. Five tarsals; arranged in two rows. The first or proximal row has two elongated, rod-like tarsals– a slightly curved and thinner **astragalus** (= tibiale) in front of tibia and a somewhat longer and thicker **calcaneum** (= fibulare) in front of fibula. The second or distal row has three small tarsals. (iv) **Metatarsals**. There are five metatarsals. (v) **Digits**. There are five digits in hindlimb. The first is called **hallux**. Each digit consists of small bones called phalanges. Digital formula of hindlimb is 2, 2, 3, 4, 3.

Urinogenital System. Since the urinogenital system comprises two closely associated **urinary** (excretory) and the **genital** (reproductive) systems, it is collectively called as the **urinogenital system.**

Excretory System

1. **Kidneys**. Kidneys of frog are **mesonephric**. Internally, each kidney is made up of a large number of minute (microscopic) tubes (about 2,000), known as **uriniferous tubules** or **nephrons**. *Each uriniferous tubule is the structural and functional unit of the kidney.*

A few ciliated funnels, the **nephrostomes**, are situated on the ventral surface of the kidney to collect the excretory matter from the coelom and pour it into the renal vein.

Each kidney contains a longitudinal **Bidder's canal** to which the transverse collecting tubules are connected. All the transverse collecting tubules lead into the ureter/urinogenital duct.

2. **Ureters/Urinogenital ducts**. From the outer border of each kidney a fine transparent duct arises, which is known as **ureter** in the female and **urinogenital duct** in the male. In female ureters carry urine alone, while in male both sperms and urine are carried from kidney to cloacal chamber hence called urinogenital ducts. Each urinogenital duct dilates to form a seminal vesicle. The latter stores the sperms temporarily. Seminal vesicles are not well-developed in *Rana tigrina*.

3. **Cloaca.** It is the terminal portion of the alimentary canal which receives faecal matter, genital products and urine. It opens outside through an opening, the **cloacal aperture**.

4. **Urinary bladder**. It is attached to the cloaca, below the opening of the ureters/urinogenital ducts. It can store the urine for some time.

Reproductive System. The sexes are separate. The male and female can be distinguished by their external features. This phenomenon is known as **sexual dimorphism**. The **vocal sacs** are present only in male, and during the breeding season, a nuptial pad is developed in the inner finger of each hand in the male frog. The vocal sacs increase the pitch of the sound, while the nuptial pads help in grasping the female during **amplexus**.

Male Reproductive System

1. **Testes**. These are two, oval yellow coloured structures. Each is lying attached on the outer side of the anteriormost part of each kidney on the ventral side. With the help of a thin peritoneum, the **mesorchium**, each testis remains attached with the dorsal wall of the abdomen and kidney.

2. **Vasa efferentia.** There are 10–12 very fine tubes connecting the testes to kidneys on each side. They open into the anterior part of **Bidder's canal**. The sperms produced by the germinal epithelium of seminiferous tubules are passed into Bidder's canal via vasa efferentia and thence carried to the transverse collecting tubules and then to the urinogenital duct via longitudinal collecting tubule.

3. **Urinogenital ducts.** Each kidney gives rise to a muscular urinogenital duct at its outer border, which carries urine as well as sperms. Each urinogenital duct runs posteriorly, and before opening into cloaca, it dilates to form a **seminal vesicle** to store the sperms temporarily. In some frogs the seminal vesicles are not found.

4. **Cloaca.** It is a common chamber for receiving faecal matter, urine and sperms. All these products are passed out through cloacal aperture. *Copulatory organ* present in higher animals, *is absent in frog.* During amplexus, the male frog sheds sperms on the female's ova. It happens in the surrounding water where external fertilization takes place.

Female Reproductive System

1. **Ovaries.** These irregular shaped, lobulated structures, occupy the same position as the testes in male frog. During breeding season, they are large and dark in colour, while in normal time, they are small and white or yellow in colour. The ovaries are attached to the dorsal wall of abdomen and kidneys with the help of thin membrane, known as **mesovarium.** The ovaries have no internal

connections with the kidneys. During the breeding season, the wall of the ovary ruptures to release the ova into the coelom.

2. **Oviducts.** These are paired, long, coiled tubes lying one on either side of the body cavity. Each oviduct consists of ovarian funnel, ovarian tubule and ovisac.

Endocrine Glands. (1) **Thyroids** (one pair). They secrete **thyroxine**. Thyroxine regulates metabolism. It also brings about **metamorphosis** (change from larva to adult). (2) **Parathyroids** (two pairs). (3) **Adrenals** (= adrenal glands — one pair). (4) **Pituitary gland** (= Hypophysis). (5) **Pineal gland** (= Epiphysis cerebri). It secretes **melatonin** hormone which influences skin colour and gonad functioning. (6) **Thymus.** (7) **Pancreas.** (8) **Stomach.** (9) **Intestine.** (10) **Testes.** There are present endocrine cells known as **interstitial cells** to secrete **sex hormone**, which brings about **secondary sexual characters** (the characters which appear only during sexual maturity) in male, *viz.*, development of **nuptial pads**. Sex hormone also influences the male behaviour during mating. (11) **Ovaries**. The ovaries not only produce ova, but also female **sex hormones** to cause secondary sexual characters in female *viz.*, she receives the male at a certain period or periods of the year.

Interaction with Mankind

Frog is useful animal for human being because it eats up insects which are harmful for the crops. Thus the frog saves expenditure on insecticides. Frog also eats mosquitoes which act as vectors for parasites (*e.g.*, malarial parasite) of man. Frog has been used as an experimental material for teaching and researches. The muscles of the legs are used as food by man in some parts of India and many other countries. Froglets (very small frogs) are used as fish bait. Due to habitat loss and large scale use of this animal, it has become a threatened species. Since frog is important animal in the food chain, it helps to maintain our ecosystem. So it should be protected.

READ AND DIGEST

- The smallest irregular bone in the skull of frog is septomaxillary.
- Longest bone of frog is tibio-fibula.
- Bones of upper jaw are premaxilla, maxilla and quadratojugal.
- Skeletal elements of lower jaw are Mento-meckalian, dentary, angulosplemiae and Meckel cartilage.
- Sinus venosus is present on the dorsal side and conus arteriosus lies on ventral side of the heart.
- Suspensorium of lower jaw from the skull is *autostylic* (more up and down because it is loosely articulated with skull).
- Atlas is the smallest vertabra in frog which looks like-ring.
- Frog has no ribs.
- Glands of Swammerdam are probably lymphoid in origin and function as reservior of calcium.
- The spleen is the largest single mass of lymphatic tissue in the body.
- Frogs are long sighted (hypermetropic) in water and short sighted (myopic) upon land.
- The frog's heart beats about 64 times per minute. Each cycle begins with the contraction of sinus venosus.
- Due to carnivorous habit, the alimentary canal of frog is short in length.
- Nerve fibres can transmit impulses at a maximum speed of about 30 meters per second in frog.

MULTIPLE CHOICE QUESTIONS

1. Which Indian scientist gave extensive information about *Pheretima* by printing a memoir ?
(1) Birbal Sahni
(2) Beni Prasad
(3) Karam Narain Bahl
(4) Har Gobind Khorana

2. Segment of earthworm bearing mouth is
(1) clitellar (2) peristomium
(3) prostomium (4) deuterostomium.

3. Prostomium is
(1) first anterior most segment
(2) outgrowth from the peristomium
(3) the second anterior most segment
(4) third anterior most segment.

4. Clitellar segments in earthworm are
(1) 13–17 (2) 14–16
(3) 15–19 (4) 14–18 *(AFMC 2010)*

5. In earthworm the buccal cavity extends upto
(1) 4th segment (2) 3rd segment
(3) 8th segment (4) 9th segment.

6. The function of typhlosole (between 26–35 segments) in earthworm is to
(1) secrete digestive juice
(2) slow down rate of passage of food
(3) increase absorptive area of intestinal epithelium
(4) have no function

7. Gizzard in *Pheretima* is an organ
(1) that secretes slime
(2) for absorption of digested food
(3) for excretion
(4) for crushing food

8. In earthworm, the stomach is situated in
(1) 8–10 segments
(2) 9–14 segments
(3) 14–26 segments
(4) 10–14 segments

9. Chromophil cells in earthworm take part in secretion of mucus and are found in
(1) Lymph gland
(2) Pharyngeal gland
(3) Blood gland (4) All

10. The flow of blood in the dorsal blood vessel of earthworm is
(1) backwards
(2) forwards
(3) backwards in half & forward in other half
(4) none of the above

11. Which statement is true about earthworm ?
(1) Blood is blue
(2) Blood is red but haemoglobin is dissolved in plasma
(3) Blood pigment is haemocyanin
(4) Blood is red but haemoglobin is dissolved in RBC's

12. In a copulating pair of earthworms, which two processes take place ?
(1) External fertilization and cross fertilization
(2) Cross fertilization and reciprocal fertilization
(3) Internal fertilization and cross fertilization
(4) Reciprocal fertilization and internal fertilization

13. In earthworm, the anterior loops are situated in
(1) 4th and 5th segments
(2) 6th and 8th segments
(3) 10th and 11th segments
(4) 12th and 13th segments.

14. Blood vascular system of earthworm is of
(1) open type (2) closed type
(3) portal type (4) none of these.

15. The smallest longitudinal blood vessel in Earthworm is
(1) dorsal blood vessel
(2) ventral blood vessel
(3) sub-neural blood vessel
(4) supra-oesophageal blood vessel.

16. Which of the blood vessel may be considered as true heart in earthworm ?
(1) Dorsal blood vessel
(2) Ventral blood vessel
(3) Supra-oesophageal blood vessel
(4) Anterior loop.

17. Four pairs of hearts in earthworm occur in segments
(1) 6, 7 and 9, 10 (2) 9, 10 and 14,15
(3) 7, 9 and 12, 13 (4) none of these.

18. In earthworm, the "forest of nephridia" is in
(1) pharyngeal region
(2) clittellar region
(3) intestinal region
(4) typhlosolar region

19. Septal nephridia of earthworm pour excretory matter into
(1) coelom (2) intestine
(3) buccal cavity (4) body surface

20. Chloragogen cells found in coelomic fluid of earthworms are analogous to vertebrate
(1) kidney (2) gut
(3) liver (4) lungs

21. Origin of nephridia in earthworm is
(1) ectodermal
(2) endodermal
(3) mesodermal (4) (2) and (3)

22. Which organ in earthworm is analogous to kidney of man ?
(1) Nephridium (2) Testis
(3) Clitellum (4) Intestine

23. Which of the following is exonephric nephridia ?
(1) Pharyngeal nephridia
(2) Septal nephridia
(3) Integumentary nephridia
(4) Integumentary and pharyngeal nephridia

24. Pharyngeal nephridia of *Pheretima* are found in segments
(1) 6, 7, 8 (2) 5, 6, 7
(3) 3, 4, 5 (4) 4, 5, 6

25. Similarity between septal nephridia and Malpighian tubule is that
(1) both excrete urea
(2) both open in body cavity
(3) both leave excretory products in alimentary canal
(4) none

26. The septal and pharyngeal nephridia open into the alimentary canal and are of enteronephric type. It is an adaptation for
(1) conservation of water
(2) conservation of heat
(3) regulation of temperature
(4) regulation of amino acids

27. Earthworm is
(1) ammonotelic (2) ureotelic
(3) uricotelic (4) both (1) & (2)

28. Which is correct about earthworm ?
(1) It can crawl on smooth surface easily
(2) It secretes cocoon around unfertilized eggs
(3) It has brain but not head
(4) It has no locomotory organs.

29. Brain in earthworm is formed of
(1) subpharyngeal ganglia
(2) infrapharyngeal ganglia
(3) suprapharyngeal ganglia
(4) all of the above

30. Nerve cord in earthworm is
(1) single, ventral, solid
(2) single, dorsal, hollow
(3) double, ventral, solid
(4) double, dorsal, hollow

31. Earthworm has
(1) no eyes (2) one eye
(3) many eyes (4) two eyes

32. Spermathecae in earthworm are found in segments
(1) 6, 7, 8, 9 (2) 4, 5, 6, 7
(3) 5, 6, 7, 8 (4) 3, 4, 5, 6

33. Which one of the following correctly describes the location of some body parts in the earthworm (*Pheretima*) ?
(1) four pairs of spermathecae in 4-7 segments
(2) one pair of ovaries attached at intersegmental septum of 14th and 15th segments
(3) two pairs of testes in 10th and 11th segments
(4) two pairs of accessory glands in 16-18 segments *(CBSE PMT 2009)*

34. Accessory glands in earthworm are found in segments
(1) 17, 18 (2) 17, 19
(3) 19, 20 (4) 18, 19

35. In earthworm, the prostate glands are
(1) one pair (2) two pairs
(3) three pairs (4) four pairs

36. Fertilization in *Pheretima posthuma* occurs in
(1) spermathecae (2) cocoon
(3) coelom (4) seminal vesicles.

37. Cocoon of earthworm can produce an average of .... worms.

(1) 16 (2) 10
(3) 8 (4) 4

38. Coelom in earthworm is
(1) schizocoelom
(2) enterocoelom
(3) both (1) and (2)
(4) pseudocoelom

39. Life span of Earthworm is
(1) 1–3 years (2) 2–8 years
(3) 3.5–10.5 years (4) 6–8 years

40. In *Pheretima* nephridia occur in
(1) all segments except 1–4 and 10–14
(2) all segments except first two segments
(3) meganephridia in pre-clitellar and micronephridia in post-clitellar segments
(4) micronephridia in all segments, meganephridia from clitellar region to end

41. Nephridia of Earthworm are analogous to
(1) nematoblasts of *Hydra*
(2) tracheae of insects
(3) flame cells of *Planaria*
(4) gills of prawn

42. Photoreceptors are unicellular in Earthworm and are most abundant in the skin of
(1) Prostomium (2) Peristomium
(3) Clitellum (4) Both (1) and (2)

43. Skeleton in *Pheretima* is
(1) bony (2) cartilaginous
(3) hydrostatic (4) dermal

44. Which one of the following is *correctly* matched regarding earthworm ?
(1) Buccal cavity – 1st to 5th segment
(2) Stomach – 11th to 12th segment
(3) Typhlosole – between 26th to 35th segment
(4) Testes – 10th to 14th segment
(5) Gizzard – 6th to 8th segment

45. Salivary gland in earthworm is found in
(1) dorsal wall of buccal cavity
(2) ventral wall of buccal cavity
(3) pharyngeal wall
(4) none of the above

46. Calciferous glands secrete
(1) Potassium (2) Phosphates
(3) Magnesium (4) Calcium

47. Blood of earthworm is red because its haemoglobin is
(1) reduced (2) oxidised
(3) intracellular (4) intercellular

48. How many "hearts" are found in earthworm ?
(1) one pair (2) 12 (six pairs)
(3) 8 (four pairs) (4) 6 (three pairs)

49. In *Pheretima* lymph glands lie in the segments
(1) 4, 5 and 6 (2) 7, 8 and 9
(3) 14, 15 and 16 (4) 26th and behind

50. Brown colour of Earthworm is due to
(1) Melanin (2) Porphyrin
(3) Haemoglobin (4) Both (1) and (2)

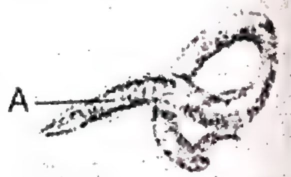
51. Type of feeding in Earthworm is
(1) fluid feeding (2) filter feeding
(3) detritus feeding (4) tentacle

52. Earthworms are
(1) ureotelic when plenty of water is available
(2) uricotelic when plenty of water is available
(3) uricotelic under conditions of water scarcity
(4) ammonotelic when plenty of water is available

53. The highly degraded organic matter rich in nitrogen and potassium in particular resulting from the activity of earthworms, is called
(1) humus
(2) vermicompost
(3) worm castings
(4) compost bedding

54. Spermathecae of earthworm take part in
(1) fertilization
(2) sperm maturation
(3) collection of sperms from other animals
(4) collection of sperms from same animals

55. In the given diagram, what does "A" represent?
(1) heart
(2) lateral vessel
(3) ventral vessel
(4) dorsal vessel



56. The gas exchange surface in an earthworm is
(1) tracheae (2) gills
(3) skin (4) ctenidia

57. A pair of male genital pores in earthworm are present on the ventro-lateral sides of the

(1) 14^{th} segment (2) 18^{th} segment
(3) 10^{th} segment (4) 15^{th} segment

58. Which are the two common Indian cockroaches ?
(1) *Periplaneta americana* & *Blatta indica*
(2) *Periplaneta indica* and *Blatta orientalis*
(3) *Periplaneta orientalis* and *Blatta americana*
(4) *Periplaneta americana* and *Blatta orientalis*.

59. *Periplaneta americana* differs from *Blatta orientalis* in
(1) well developed wings
(2) wings absent
(3) only first pair of wings developed
(4) second pair of wings developed

60. The wings which are used for flying in cockroach are
(1) both pairs of wings (2) fore wings
(3) hind wings (4) none of these

61. The correct arrangement of leg parts is
(1) coxa, femur, trachanter, tibia and claws
(2) coxa, trochanter, femur, tibia, tarsus and claws
(3) coxa, tibia, femur, plantulae and claws
(4) none

62. Plantulae, the adhesive pads, are found in
(1) coxa (2) trochanter
(3) femur (4) tarsus

63. Most swollen segment in leg in cockroach is
(1) tarsus (2) coxa
(3) femur (4) trochanter

64. Trichogen cell in the body wall secretes
(1) epicuticle (2) exocuticle
(3) endocuticle (4) cuticular seta

65. The flagellum of antenna of cockroach is
(1) 11 jointed (2) 13 jointed
(3) unjointed (4) many jointed

66. Arolium in cockroach helps in
(1) digestion (2) locomotion
(3) respiration (4) reproduction

67. The dorsal plate of skeleton found on the abdomen of cockroach is called
(1) pleuron (2) sternum
(3) tergum (4) vertex

68. Secretion of stink glands helps in
(1) attracting the preys
(2) repelling enemies
(3) killing the preys
(4) none of the above

69. Mouth parts of cockroach are suited for
(1) piercing (2) absorbing
(3) biting and chewing (4) drinking

70. The labium in cockroach is formed by
(1) first maxillae (2) second maxillae
(3) mentum (4) submentum

71. Mandibles of cockroach are
(1) short with grinding teeth
(2) long and pointed
(3) short without teeth
(4) long and coiled

72. Cells of cockroach that secrete wax are
(1) trichogen (2) trophocytes
(3) myocytes (4) oenocytes

73. Peritrophic membrane is secreted by
(1) crop (2) gizzard
(3) mid gut (4) ileum

74. Function of rectal papillae of cockroach is
(1) absorption of amino acids
(2) absorption of fats
(3) absorption of glucose
(4) absorption of water

75. Salivary glands of cockroach open on
(1) maxilla (2) hypopharynx
(3) labium (4) labrum

76. The body cavity of cockroach is called
(1) pseudocoel (2) coelom
(3) hydrocoel (4) haemocoel

77. Haemoglobin is not found in
(1) Duck
(2) Lizzard (3) Earthworm
(4) Mosquito and cockroach.

78. Tergosternal muscles help in
(1) circulation (2) respiration
(3) flight (4) all of these

79. Number of chambers in the heart of cockroach is
(1) 5 (2) 9
(3) 13 (4) 16

80. Alary muscles in cockroach are connected with
(1) trachea (2) dorsal diaphragm
(3) legs (4) alimentary canal

81. One common feature of the trachea of cockroach and the trachea of mammals is that
(1) both are paired
(2) both have ciliated inner lining
(3) both originate from the head region
(4) both have non-collapsible walls.

82. Tracheoles of cockroach are
(1) with cuticular rings
(2) without cuticular rings
(3) with cuticular rings and tissue fluid
(4) without cuticular rings and with tissue fluid.

83. A common character between septal nephridia of earthworm and Malpighian tubules of cockroach is that both
(1) have ciliated funnels
(2) discharge into alimentary canal
(3) are segmental structures
(4) discharge directly outside body.

84. Maphighian tubules are found on the
(1) distal region of mesenteron
(2) proximal region of mesenteron
(3) proximal region of proctodaeum
(4) junction of mesenteron & proctodaeum

85. Number of thoracic and abdominal ganglia in cockroach respectively is
(1) six, three (2) six, six
(3) three, six (4) three, three

86. Structural and functional units of compound eye of cockroach used in forming image are called
(1) ocelli (2) rhabdomes
(3) ommatidia (4) retinulae

87. Which type of vision is found in cockroach ?
(1) Binocular (2) Monocular
(3) Panaromic (4) Mosaic

88. Number of ommatidia in each eye of cockroach is
(1) 1000 (2) 2000
(3) 3000 (4) 4000

89. An ommatidium consists of
(1) dioptrical region
(2) receptive region
(3) both (1) and (2)
(4) none of these

90. Phallic gland (conglobate gland) of cockroach mainly helps in
(1) formation of spermatophores
(2) reproduction
(3) growth (4) excretion

91. Left phallomere consists of
(1) accutolobus (2) titillator
(3) pseudopenis and asperate lobe
(4) all the above

92. How many ovarioles are found in each ovary of cockroach ?
(1) 3 (2) 6 (3) 8 (4) 16

93. Collateral glands of cockroach help in
(1) fertilization
(2) formation of ootheca
(3) copulation
(4) formation of oothecal chamber

94. Ecdyoson is secreted by
(1) prothoracic glands
(2) corpora allata
(3) corpora cardiaca
(4) cerebral-neuro-secretory cells.

95. Utricular gland is found in
(1) Female cockroach
(2) Male cockroach
(3) Scorpion (4) Spider

96. Nymph, the young cockroach, differs from adult cockroach in
(1) being smaller in size
(2) devoid of wings
(3) having gonads
(4) all of these

97. The interval between two ecdyses is called
(1) stadium (2) instar
(3) imago (4) none of these

98. In cockroach fertilization occurs in the
(1) oothecal chamber
(2) genital chamber
(3) oviducts
(4) spermathecae

99. Eggs which have yolk in the centre surrounded by cytoplasm are called
(1) centrolecithal (2) homolecithal
(3) microlecithal (4) alecithal

100. The wall of spermatophore consists of
(1) one layer (2) two layers
(3) three layers (4) four layers

101. Ootheca of cockroach has fertilized eggs, their number is
(1) 6 (2) 8 (3) 16 (4) 24

102. Metamorphosis in cockroach is regulated mainly by
(1) corpora cardiaca
(2) prothoracic glands
(3) corpora allata
(4) brain

103. Life history of cockroach represents
(1) ametaboly (2) holometaboly
(3) paurometaboly (4) none of these

104. Which part of Cockroach has both exoskeleton and endoskeleton ?
(1) Head (2) Thorax
(3) Abdomen (4) All of these

105. In cockroach the longest podomere is
(1) coxa
(2) trochanter or Femur
(3) tibia (4) tarsus

106. Eggs of cockroach are
(1) homolecithal (2) telolecithal
(3) centrolecithal (4) meiolecithal

107. Which of the following is absent in the leg of cockroach ?
(1) Coxa (2) Tibia
(3) Femur (4) fibula

108. The largest part of the alimentary canal of cockroach is
(1) crop (2) ileum
(3) rectum (4) mesenteron

109. Hepatic caecae in cockroach are derived from
(1) crop (2) ileum
(3) mid gut (4) oesophagus

110. In cockroach, the cuticular lining of trachea is called
(1) intima (2) serosa
(3) articular membrane
(4) peritoneum

111. Atrium of *Periplaneta* is a
(1) tracheal ring
(2) tube of trachea
(3) cavity below spiracle
(4) fluid filled in trachea

112. Peritreme in cockroach is
(1) tracheal network
(2) stigmatal opening
(3) one of the abdominal segments
(4) annular sclerite surrounding spiracle

113. Phallomeres are
(1) structures present in the head of house fly
(2) external genitalia in cockroach
(3) vestigial wings in female cockroach
(4) parts of mouth parts of house fly

114. Heart of cockroach is
(1) myogenic (2) photogenic
(3) neurogenic (4) morphogenic

115. Pericardial space in cockroach can be altered by movements of which of the following muscles ?
(1) Allary (2) Circular
(3) Ciliary (4) Longitudinal

116. The taste receptors of cockroach are
(1) tactile hairs (2) compound eyes
(3) companiform sensillae
(4) palps of maxillary and labium

117. Blood of cockroach does not contain haemoglobin because
(1) it does not respire
(2) it respires through book lungs
(3) it respires through atmosphere
(4) it has some other means to carry oxygen direct into the tissue

118. Abdominal ganglion in cockroach is not found in this segment (s).
(1) 2 and 3 (2) 4
(3) 5 (4) 6

119. Phallomeres in male *Periplaneta* arise from
(1) 7th sternum (2) 8th sternum
(3) 9th sternum (4) 8 and 9th sterna

120. Antennae of cockroach function as
(1) auditory receptor
(2) gustatory recepter
(3) olfactory receptor
(4) tactile sensory receptor

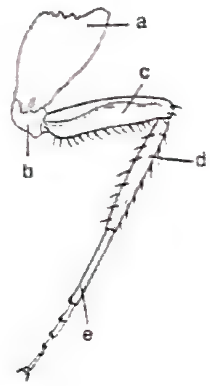
121. Fat body of cockroach has
(1) Trophocytes (2) Mycetocytes
(3) Oenocytes (4) Urate
(5) All of these

122. In cockroach the corpora allata secrete
(1) brain hormone (2) growth hormone
(3) juvenile hormone (4) ecdyson

123. In cockroach, the anterior wings are called
(1) Elytra (2) Pedipalps
(3) Antenna (4) Chelicera

124. Ingluvial ganglion in cockroach is present on the surface of
(1) crop (2) gizzard
(3) brain (4) none of these

125. In the following diagram of a leg of cockroach parts have been indicated by alphabets. Choose the answer in which these alphabets have been correctly matched with the parts they indicate.



(1) a = coxa, b = tibia, c = tarsus, d = femur, e = trochanter
(2) a = coxa, b = femur, c = trochanter, d = tarsus, e = tibia
(3) a = coxa, b = tarsus, c = femur, d = tibia, e = trochanter
(4) a = coxa, b = trochanter, c = femur, d = tibia, e = tarsus

126. *Periplaneta americana* has thermoreceptor sensillae on
(1) 1st, 2nd and 3rd segments of tarsus of legs
(2) 3rd, 4th and 5th segments of tarsus of legs
(3) 15th segment of anal cerci
(4) Pedicel of antenna

127. Cockroach has a stomodaeal valve between
(1) ileum and colon
(2) crop and gizzard
(3) mesenteron and ileum
(4) gizzard and mesenteron

128. What is the main difference between male and female cockroach ?
(1) jointed appendages
(2) paired antennae
(3) anal cerci
(4) conglobate gland

129. A pair of stink gland is found in
(1) 4th and 5th terga of cockroach
(2) 5th and 6th terga of cockroach
(3) 5th and 6th sterna of cockroach
(4) 4th and 5th sterna of cockroach

130. Which of the following hormones regulates growth and metamorphosis in insect ?
(1) Juvenile hormone
(2) Brain hormone
(3) Ecdyson
(4) Prothoracicotropic hormone

131. Malpighian tubules ae analogous to
(1) trachea of cockroach
(2) gills
(3) flame cells (4) none of these

132. In the larva of frog the respiration is carried out by
(1) gills (2) lungs
(3) skin (4) skin and gills.

133. In frog which are the typical vertebrae, numbering ....
(1) 1st (2) 2nd to 7th
(3) 8th and 9th (4) All of these

134. In frog the type of teeth are
(1) acrodont (2) heterodont
(3) pleurodont (4) thecodont

135. If the mouth of a frog is kept open for some time, it dies because it is unable to
(1) breathe (2) drink water
(3) feed (4) utilize excess of air

136. In frog the typical vertebrae are
(1) procoelous (2) acoelous
(3) amphicoelous (4) amphiplatyan.

137. In frog the skin colour is due to
(1) upper layer of yellow lipophores
(2) middle layer of guanophores
(3) lowest layer of melanophores
(4) all of the above

138. The kidneys of frog are
(1) holonephros (2) mesonephros
(3) metanephros (4) pronephros

139. Metamorphosis in frog can be accelerated by
(1) I_2 (2) P (3) K (4) Ca

140. Frog is dissected from posterior side because
(1) it is convenient
(2) that side possess ventral cord
(3) due to abdominal vein
(4) posterior side is soft to cut

141. The integument of the frog is always kept moist because
(1) it cannot move with dry skin
(2) it performs cutaneous respiration
(3) it cannot catch food with dry skin
(4) it cannot jump better with moist skin

142. Bone of the shank in frog is called
(1) femur (2) tibio-fibula
(3) humerus (4) radio-ulna

143. Oval and nucleated RBC is found in
(1) man (2) rat
(3) rabbit (4) frog

144. Male frogs can croak louder than females because of
(1) larger in size (2) larger sound box
(3) stronger (4) vocal sacs

145. In frog the phalangeal formula for hand is
(1) 0, 2, 2, 3, 3 (2) 2, 2, 3, 4, 3
(3) 2, 2, 3, 3, 4 (4) 2, 3, 3, 3, 3.

146. The phalangeal formula for frog's foot is
(1) 0, 2, 3, 3, 3 (2) 2, 2, 3, 3,4
(3) 2, 2, 3, 4,3 (4) 2, 3, 3, 3,3.

147. In frog, the biggest bone of vertebral column is
(1) pygostyle (2) uropyge
(3) urostyle (4) none of these.

148. Lower jaw is toothless in
(1) Cockroach (2) Frog
(3) Rabbit (4) None of these

149. The functional kidney of frog tadpole is
(1) archinephros (2) pronephros
(3) mesonephros (4) metanephros

150. Croaking of Frog is
(1) hunger call (2) sex call for female
(3) danger call (4) musical note

151. Absence of thumb is characteristic of
(1) rabbit (2) man
(3) frog (4) monkey

152. How many vertebrae a frog has including urostyle ?
(1) 10 (2) 9 (3) 8 (4) 33

153. Astragalus and calcaneum are found in
(1) fore limb of frog (2) hind limb of frog
(3) wing of bird (4) skull of rabbit.

154. Longest bone of frog is
(1) humerus (2) femur
(3) radio-ulna (4) tibio-fibula

155. In frog, the jaw suspensorium is
(1) craniostylic (2) autostylic
(3) hyostylic (4) amphistylic

156. Humerus differs from femur in having a
(1) sigmoid notch (2) glenoid cavity
(3) deltoid ridge (4) spine

157. Which embryonic structure is replaced by vertebral column in frog ?
(1) Neural canal (2) Archenteron
(3) Notochord (4) Blastocoel

158. When a frog is in hibernation or completely submerged in water it can respire only through
(1) lungs (2) skin
(3) branchial chamber
(4) buccopharyngeal cavity

159. In the heart of frog, which of the following is considered as pacemaker ?
(1) Pylangium (2) Synangium
(3) Sinuauricular node
(4) Truncus arteriosus

160. Frog differs from man in
(1) having both renal and hepatic portal systems
(2) not having renal portal system
(3) having hepatic portal system
(4) not having hepatic portal system.

161. In frog each cardiac cycle begins with the contraction of
(1) right auricle (2) left auricle
(3) interauricular septum
(4) sinus venosus

162. Bidder's canal is found in
(1) kidney of male frog (2) testis of frog
(3) liver of frog (4) ovaries of frog

163. Funnel-like ciliated pits on the ventral side of the kidney in frog are known as
(1) nephridiopores (2) nephrostomes
(3) neurotomes (4) coelomostomes

164. Glands of Swammerdam are associated with frog's
(1) cranial nerves (2) spinal nerves
(3) sympathetic nerves
(4) parasympathetic nerves

165. Total number of cranial nerves in frog is
(1) 10 (2) 20 (3) 24 (4) 12

166. Harderian glands are found in
(1) Rabbit (2) Frog
(3) Man (4) *Pheretima*

167. In frog sclerotic is
(1) fibrous (2) cartilaginous
(3) bony (4) membranous

168. Frog has
(1) tear glands (2) oil glands
(3) columella auris (4) sweat glands

169. Which gland initiates, regulates and plays a key role in metamorphosis of frog's tadpole?
(1) Adrenal (2) Pancreas
(3) Thyroid (4) Thymus

170. Epiphysis cerebri is another name for
(1) pituitary (2) pineal gland
(3) optic lobes (4) diencephalon

171. In Frog, jelly around the eggs is deposited
(1) in water after fertilization
(2) in water during fertilization
(3) in the oviduct (4) in the ovary

172. Opening of rectum in Frog is called
(1) coccyx (2) cloaca
(3) anus (4) none of these

173. In frog, 'fenestra ovalis' is
(1) the opening in the auditory capsule which separates the middle ear from the inner ear.
(2) the air filled cavity of the middle air.
(3) the communication between the pharynx and the tympanic cavity.
(4) the external opening of the tympanic cavity which is covered by the tympanic membrane

174. Which artery is absent in frog ?
(1) Right systemic arch
(2) Phrenic artery
(3) Carotid artery (4) Renal artery

175. Structure present in man but absent in frog is
(1) salivary gland (2) pancreas
(3) adrenal glands (4) thyroid gland

176. Adrenaline and nor-adrenaline are hormones and also act as
(1) energy-producing agents
(2) neurotransmitters
(3) food-storage materials
(4) energy-storing substances

177. In Frog, oviduct is modification of
(1) Wolffian duct (2) Bidder's canal
(3) Metanephric duct (4) Mullerian duct

178. In frog the surface of attachment of tongue is
(1) palatine (2) sphenoid
(3) pterygoid (4) hyoid apparatus

179. Which of the following structures are absent in forelimb of frog ?
(a) Brachium (b) Web
(c) Antebrachium (d) Tarsal
(1) (a) and (b) are correct
(2) (b) and (d) are correct
(3) (a) and (c) are correct
(4) (a), (b) and (c) are correct

180. Nitrogenous waste products are eliminated mainly as
(1) urea in tadpole and uric acid in adult frog
(2) urea in adult frog and ammonia in tadpole
(3) urea in tadpole as well as in adult frog
(4) urea in tadpole and ammonia in adult frog

181. The epithelial lining of the alveoli of frog's lung facing lung cavity is
(1) columnar, non-ciliated
(2) columnar, ciliated
(3) squamous, ciliated
(4) squamous, non-ciliated

182. In frog caudal vertebrae are fused to form
(1) coccyx (2) urostyle
(3) pygostyle (4) prehensile tail

183. What is not found in skin of frog ?
(1) scales (2) epidermis
(3) poison glands (4) mucus glands

184. Which of the following is not a part of the small intestine of frog ?
(1) Ileum (2) Jejunum
(3) Duodenum (4) none of these

185. In frog, smallest bone in the skull is
(1) septomaxillary (2) vomer
(3) parasphenoid (4) exoccipital

186. Which of these is an ear-ossicle in frog ?
(1) Incus (2) Auricle
(3) Malleus (4) Columella auris

187. Select the correct order of classification of *Rana tigrina* upto genus
(1) Gnathostomata, Craniata, Chordata, Rana, Tigrina
(2) Chordata, Craniata, Amphibia, Gnathostomata, Rana
(3) Chordata, Craniata, Gnathostomata, Amphibia, Rana
(4) Chordata, Amphibia, Gnathostomata, Craniata, Tigrina
(5) Chordata, Craniata, Amphibia, Gnathostomata, Tigrina

188. The cloaca in frog is a common chamber for the urinary tract, reproductive tract and

(1) alimentary canal (2) notochord
(3) portal system
(4) lymphatic system
(5) hepatic portal vessels

189. In frog, two phalanges occur in
(1) pollex (2) hallux
(3) third finger (4) third toe

190. Part of stomach which opens into duodenum is
(1) cardiac (2) pyloric
(3) fundus (4) body

191. Which one of the following is **not** a characteristic feature of frog ?
(1) The skin is moist and slimy
(2) Each of the fore limbs and hind limbs end in five digits
(3) Hepatic portal and renal portal systems are present
(4) Skin, buccal cavity and lungs are respiratory organs
(5) Heart is three chambered

192. Innominate is
(1) a nerve (2) an artery
(3) a vein
(4) a part of skeleton and an artery

193. The anterior abdominal vein in frog is formed by the union of
(1) femoral vein (2) sciatic vein
(3) renal vein (4) pelvic vein

194. Skin is an accessory organ of respiration in
(1) human (2) frogs
(3) rabbit (4) lizard *(WB JEE 2010)*

195. The respiratory rhythm centre is present in the
(1) cerebrum (2) cerebellum
(3) hypothalamus
(4) corpora quadrigemina
(5) medulla oblongata *(Kerala PMT 2010)*

196. V cranial nerve of frog is
(1) facial (2) olfactory
(3) trigeminal (4) vagus
(AFMC 2010)

197. How many ova are laid at a time by a mature female frog?
(1) 500 to 1000 (2) 1000 to 1500
(3) 2500 to 3000 (4) 3500 to 4500
(HP PMT 2010)

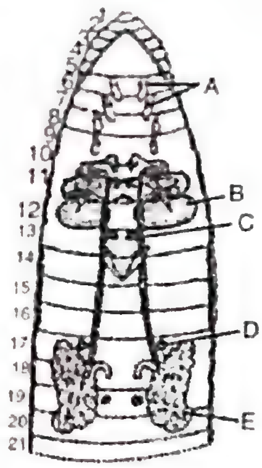
198. Male and female cockroaches can be distinguished externally by
(1) Anal styles in male
(2) Anal cerci in female
(3) Anal style and antennae in female
(4) Both 2 and 3 *(HP PMT 2010)*

*199. Which one of the following species of earthworm is not recommended for vermicomposting ?
(1) *Eudrilus eugeniae*
(2) *Eisenia fetidae*
(3) *Pyrionyx excavatus*
(4) *Pheretima posthuma*
(Karnataka CET 2010)

200. Cockroaches can climb smooth or steep surfaces due to the adhesive pads found on the torses of their legs. They are called ....
(1) plantulae (2) tibia
(3) pretarsus (4) arolium
(Karnataka PMT 2010)

201. The abdomen of adult cockroaches has ______ segments.
(1) 4 (2) 6 (3) 8 (4) 10
(Chandigarh CET 2010)

202. In the diagram of the reproductive system of earthworm A, B, C, D and E represent



(1) A. seminal vesicle, B. spermathecae, C. prostate gland, D. ovary, E. accessory gland
(2) A. seminal vesicle, B. ovary, C. accessory gland, D. spermathecae, E. prostate gland

*199. *Lumbricus terrestres* is an earthworm species which is considered to be a serious pest species. Other two are also species of earthworm.

(3) A. spermathecae, B. seminal vesicle, C. accessory gland, D. ovary, E. prostate gland
(4) A. spermathecae, B. seminal vesicle, C. ovary, D. accessory gland, E. prostate gland
(5) A. ovary, B. seminal vesicle, C. accessory gland, D. prostate gland, E. spermathecae *(Kerala PMT 2011)*

203. In earthworms setae are present in all segments except
(1) first and the last segments
(2) first and the clitellum
(3) first segment
(4) clitellum and last segments
(5) first clitellum and last segments *(Kerala PMT 2011)*

204. About how many times does the nymph of the *Periplaneta americana* undergo moulting before becoming an adult ?
(1) 4 (2) 2 (3) 17 (4) 4
(5) 13 *(Kerala PMT 2011)*

205. Which one of the following structures in *Pheretima* is correctly matched with its function ?
(1) Typhlosole – storage of extra nutrients
(2) Clitellum – secretes cocoon
(3) Gizzard – absorbs digested food
(4) Setae – defence against predators *(AIPMT (Mains) 2011)*

206. The breakdown of detritus into smaller particles by earthworm is a process called
(1) humification (2) fragmentation
(3) mineralisation (4) catabolism *(AIPMT Mains 2011)*

207. Ureters act as urinogenital ducts in
(1) frog's males
(2) human males
(3) human females
(4) frog's both males and females *(AIPMT (Mains) 2011)*

208. Read the statements with regard to frog. Which of the statement (s) is/are correct and incorrect ?
A. The medulla oblongata passes out through foramen of Monro and continues into spinal cord.
B. Vasa efferentia are 10-12 in number that arise from testes.
C. Ovaries have no functional connection with kidneys.
D. Frogs are uricotelic.
(1) A, B and C are correct but D is incorrect
(2) A and B are correct while C and D are incorrect
(3) B and C are correct while A and D are incorrect
(4) B, C and D are correct while A is incorrect
(5) C and D are correct while A and B are incorrect *(Kerala PMT 2011)*

209. The tympanic cavity, in frog communicates with pharynx ventrally through
(1) bidder's canal
(2) horizontal canal
(3) semicircular canal
(4) eustachian tube *(AMU Medical 2011)*

210. Fertilization in frog is
(1) external (2) internal
(3) both (4) none of these *(AMU Medical 2011)*

211. Compound eyes are found in
(1) frog (2) earthworm
(3) cockroach (4) roundworm *(AMU (Medical) 2011)*

212. How do you differentiate a frog from a toad ?
(1) frog has no exoskeleton but toad has scales
(2) frog respires through lungs but toad respires through skin
(3) frog has a tail but toad has no tail
(4) frog has no parotid glands but toad has a pair of parotid glands *(Karnataka CET 2011)*

213. The open circulatory system is found in
(1) earthworm (2) cockroach
(3) snail (4) both (2) and (3) *(Orissa JEE 2011)*

214. Which of the following happens in the common cockroach ?
(1) Malpighian tubules are excretory organs projecting out from the colon
(2) Oxygen is transported by haemoglobin in blood
(3) Nitrogenous excretory product is urea
(4) The food is ground by mandibles and gizzard *(AIPMT (Prelims) 2011)*

*215. In cockroach, the gizzard contains
(1) Four teeth (2) Six teeth
(3) Five teeth (4) Eight teeth
(HP PMT 2011)

216. Which one of the following characteristic is common both in humans and adult frogs ?
(1) Four chambered heart
(2) Internal fertilization
(3) Nucleated RBCs
(4) Ureotelic mode of excretion
(CBSE PMT Prelims 2012)

217. In the mouth parts of cockroach the galea and lacinia form parts of the
(1) mandibles (2) maxillae
(3) labium (4) labrum *(AMU 2012)*

218. The ovaries in frog open into cloaca through
(1) Bidder's canal (2) Urinogenital duct
(3) Single oviduct (4) A pair of oviducts
(HP PMT 2012)

219. Special venous connection between the heart and the liver in frogs is the
(1) Renal portal system
(2) Lymphatic system
(3) Hepatic portal system
(4) Pulmonary system *(HP PMT 2012)*

220. Seminal vesicles in Pheretima are located in the segments
(1) 4 & 5 (2) 3 & 4
(3) 14 & 15 (4) 11 & 12
(HP PMT 2012)

221. Blood glands in Pheretima are present in these segments
(1) 3^{rd} & 4^{th} only (2) 14^{th} & 15^{th}
(3) 4^{th}, 5^{th} & 6^{th} (4) 12^{th} & 13^{th}
(HP PMT 2012)

222. Mushroom gland in cockroach is located in
(1) $2^{nd} - 5^{th}$ segments
(2) $3^{rd} - 5^{th}$ segments
(3) $6^{th} - 7^{th}$ segments
(4) $7^{th} - 8^{th}$ segments *(HP PMT 2012)*

223. Cockroach is
(1) Ureotelic (2) Ammonotelic
(3) Uricotelic (4) proteinotelic
(HP PMT 2012)

*224. The body cells in cockroach discharge their nitrogenous waste in the haemolymph mainly in the form of
(1) Ammonia (2) Potassium urate
(3) Urea (4) Calcium carbonate

225. What external changes are visible after the last moult of a cockroach nymph?
(1) Both fore wings & hind wings develop
(2) Labium develops
(3) Mandibles become harder
(4) Anal cerci develops *(NEET 2013)*

226. The terga, sterna and pleura of cockroach body are joined by
(1) muscular tissue
(2) arthrodial membrane
(3) cartilage
(4) cementing glue *(AIPMT 2015)*

227. In male cockroaches, sperms are stored in which part of the reproductive system?
(1) Seminal vesicles
(2) Mushroom glands
(3) Testes
(4) Vas deferens *(NEET-2-2016)*

*215. Teeth are Chitinous plates which help in grinding.
*224. Cockroach is uricotelic.

ANSWERS

1. (3)	2. (2)	3. (2)	4. (2)	5. (2)	6. (3)	7. (4)	8. (2)	9. (2)	10. (2)
11. (2)	12. (2)	13. (3)	14. (2)	15. (4)	16. (1)	17. (3)	18. (2)	19. (2)	20. (3)
21. (1)	22. (1)	23. (3)	24. (4)	25. (3)	26. (1)	27. (4)	28. (3)	29. (3)	30. (3)
31. (1)	32. (1)	33. (3)	34. (2)	35. (1)	36. (2)	37. (4)	38. (1)	39. (3)	40. (2)
41. (3)	42. (4)	43. (3)	44. (3)	45. (3)	46. (4)	47. (4)	48. (3)	49. (4)	50. (2)
51. (3)	52. (4)	53. (2)	54. (3)	55. (4)	56. (3)	57. (2)	58. (4)	59. (1)	60. (3)
61. (2)	62. (4)	63. (2)	64. (4)	65. (4)	66. (2)	67. (3)	68. (2)	69. (3)	70. (2)
71. (1)	72. (4)	73. (3)	74. (4)	75. (2)	76. (4)	77. (4)	78. (4)	79. (3)	80. (2)
81. (4)	82. (4)	83. (2)	84. (4)	85. (3)	86. (3)	87. (4)	88. (2)	89. (3)	90. (1)
91. (4)	92. (3)	93. (2)	94. (1)	95. (2)	96. (4)	97. (1)	98. (2)	99. (1)	100. (3)
101. (3)	102. (2)	103. (3)	104. (1)	105. (4)	106. (3)	107. (4)	108. (1)	109. (3)	110. (1)
111. (3)	112. (4)	113. (2)	114. (3)	115. (1)	116. (4)	117. (4)	118. (3)	119. (3)	120. (4)
121. (5)	122. (3)	123. (1)	124. (1)	125. (4)	126. (1)	127. (4)	128. (4)	129. (2)	130. (3)
131. (3)	132. (4)	133. (2)	134. (1)	135. (1)	136. (1)	137. (4)	138. (2)	139. (1)	140. (3)
141. (2)	142. (2)	143. (4)	144. (4)	145. (1)	146. (3)	147. (3)	148. (2)	149. (2)	150. (2)
151. (3)	152. (1)	153. (2)	154. (4)	155. (2)	156. (3)	157. (3)	158. (2)	159. (3)	160. (1)
161. (4)	162. (1)	163. (2)	164. (2)	165. (2)	166. (2)	167. (2)	168. (3)	169. (3)	170. (2)
171. (3)	172. (3)	173. (1)	174. (2)	175. (1)	176. (2)	177. (4)	178. (4)	179. (2)	180. (2)
181. (2)	182. (2)	183. (1)	184. (2)	185. (1)	186. (4)	187. (3)	188. (1)	189. (2)	190. (2)
191. (2)	192. (4)	193. (4)	194. (2)	195. (5)	196. (3)	197. (3)	198. (1)	199. (2)	200. (1)
201. (4)	202. (4)	203. (5)	204. (5)	205. (2)	206. (2)	207. (1)	208. (3)	209. (4)	210. (1)
211. (3)	212. (4)	213. (4)	214. (4)	215. (2)	216. (4)	217. (2)	218. (4)	219. (3)	220. (4)
221. (3)	222. (3)	223. (2)	224. (2)	225. (1)	226. (2)	227. (1)			

8 CELL — THE BASIC UNIT OF LIFE

As observed by Lamarck (1809), *no body can have life if its constituent parts are not formed of cells*. Cell theory further elaborated the role of cells. According to cell theory, all organisms are formed of cells and that new cells develop from pre-existing ones. Study of form, structure and composition of cells is called **cytology**. Branch of biology that deals with various aspects of structure, chemistry, development, genetics and functioning of cells is called **cell biology**. In cell biology, scientists study fundamental processes that are common to all cells and are akin to studying various life processes. Cell biology is, therefore, a unifying subject.

Basic Unit

Cell is a basic unit of life as no living organism can have life without being cellular because cell is a unit of both its structure and function. All life begins as a single cell. A number of organisms are made of single cells. They are called **unicellular or acellular**, *e.g.*, *Amoeba, Chlamydomonas, Acetabularia*, bacteria, yeast. Here a single cell is (i) capable of independent existence and (ii) able to perform all the essential functions of life. Anything less than a complete cell can neither lead an independent existence nor perform all the functions of life. A **multicellular organism** is made of many cells. A higher animal or plant contains billions of cells. For example, a newly born human infant has 2×10^{12} cells. The number increases to 100 trillion (100×10^{12} or 10^{14}) cells in the body of 60 kg human being. About 25% (25×10^{12}) of them are found in the blood. A drop of blood contains several million cells. The large sized organisms do not have large sized cells. Instead they possess higher number of cells. In multicellular organisms, cells are **building blocks** of the body or basic units of body structure. Of course, they become specialized for performing different functions. Human body has some 200 types of cells, *e.g.*, erythrocytes, leucocyte types, epithelial cell types, muscle cells, nerve cells, fat cells, cartilage cells, bone cells, connective tissue cells, gland cells, germinal cells, pigment cells, etc. Cells are grouped into tissues, tissues into organs and organs into organ systems. Occurrence of different types of tissues, organs and organ system results in **division of labour** or performance of different functions of the body by specialised structures.

Cells are not only the building blocks of the organisms, they are also the **functional units** of life. Life passes from one generation to the next in the form of cells. The activities of an organism are actually the sum total of activities of its cells. Each cell of the body possesses the same genetic information though mature cells may become specialized to perform specific functions. A new cell always develops by division of a pre-existing cell. Cells are **totipotent**, *i.e.*, a single cell has the ability to form the whole organism. Internally each cell is build up of several organelles. The organelles perform different functions just like the ones carried on by different organ systems of the body. All life activities of the organism are present in miniature form in each and every cell of its body. Thus, cell is a **basic unit of life** and **structural and functional unit of an organism.** It is the **smallest** unit capable of **independent** existence and performing the **essential functions** of life.

Discovery of Cell

Work on the study of cell has continued for more than the last three and a half centuries. It required **microscopes** or instruments with good resolving power and magnification. Techniques like preservation, sectioning, staining and mounting were needed to distinguish various cellular components. Improvement in tools and techniques has continued all this period to enhance our knowledge about the cell.

The first microscope was built by Zacharias Janssen in 1590. It was first modified by Galileo (1610) and then by Robert Hooke (Fig. 8.1). Robert Hooke (1635–1703) was a mathematician and physicist. He developed a new microscope with which he studied the internal structure of a number of plants. His work is famous for the study of cork cells. In 1665, Robert Hooke wrote a book "**Micrographia** : or *Some Physiological Descriptions of Minutae made by magnifying glasses with observations and enquiries there upon.*" The chapter which gave birth to cell biology is "*Observe XVIII : of the schematisme or texture of cork and of the cells and pores of some other such frothy bodies*". He took a piece of cork of spanish oak and prepared thin slice by means of sharp pen knife. A deep planoconcave lens was used for throwing light on cork piece. The latter was observed under the microscope (Fig. 8.1). The piece of cork was found to have a honey comb structure with a number of box like compartments, each having a pore and separated from others by diaphragms (Fig. 8.2). Robert Hooke named the compartments as **cellulae** (singular– cellula) now known as **cells** (Latin *cella* – hollow spaces or compartments). He did not know the significance of these structures and regarded them as passages for conducting fluids. Actually the 'cells' of Hooke were cell walls enclosing spaces left by dead protoplasts. Robert Hooke found that the cells or boxes were not very deep. A cubic inch contained 1259,712,000 cells, a square inch 1,66,400 and one inch strip 1080 cells. The term "cell" is actually a **misnomer** as a living cell is neither hollow nor always covered by a wall.

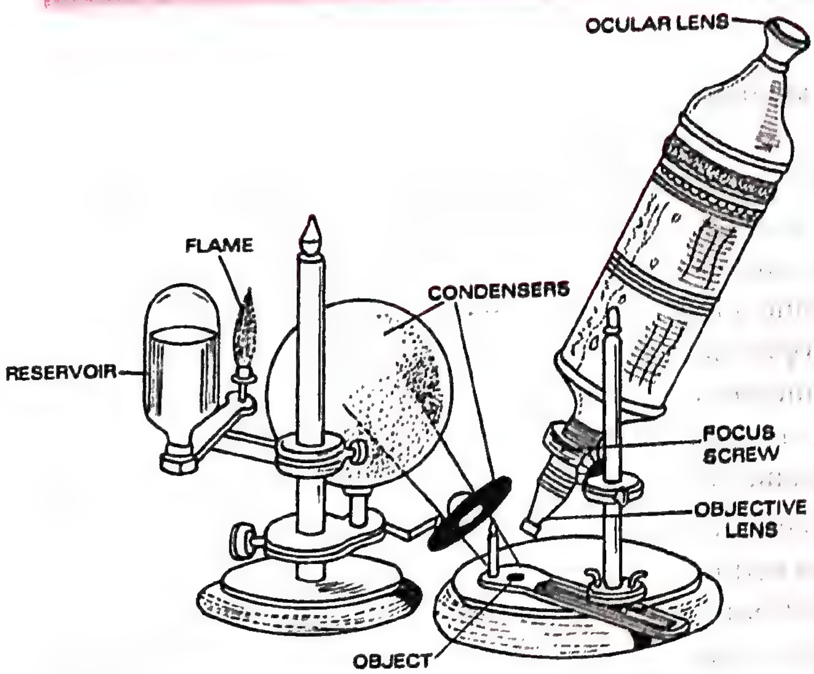


Fig. 8.1. The crude microscope employed by Robert Hooke (1665).

Cells were also observed prior to Hooke, by Malpighi (1661), who called them saccules and utricles. **Leeuwenhoek** (1673) was first to observe, describe and sketch a free living cell. He observed bacteria, protozoa, spermatozoa, red blood cells, etc. In the beginning of nineteenth century it became clear that the bodies of organisms are made of one or more cells. Robert Brown (1831) discovered the presence of

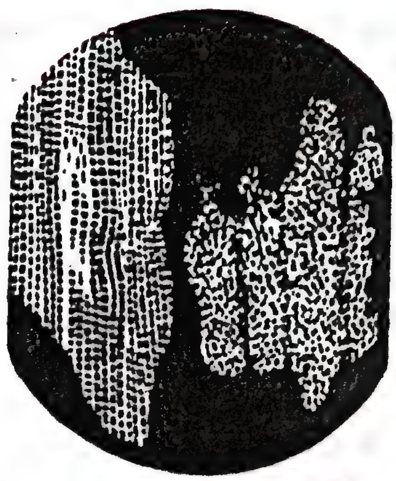


Fig. 8.2. Drawing of cork cells by Robert Hooke (1665).

nucleus in the cells of orchid root. Living semifluid substance of cells was discovered by Dujardin (1835) and named sarcode. Schleiden (1838) found all plant cells to have similar structure— cell wall, a clear jelly-like substance and a nucleus. Schwann (1838) discovered that animal cells lacked cell wall. Purkinje (1839) and von Mohl (1838, 1846) renamed sarcode or the jelly like substance of the cells as **protoplasm** (Gk. *protos*– first, *plasma*– form). Cell membrane was discovered by Schwann (1838) but was provided with a name by Nageli and Cramer (1855). Soon various organelles were discovered inside the cells. Electron microscope has elaborated our knowledge about cells.

Cell Theory

The theory was jointly put forward by Schleiden and Schwann (1839) in their paper "*Microscope Investigations on the similarity of structure and growth in animals and plants.*" Cell theory states that the bodies of all organisms are made up of cells and their products so that cells are units of both structure and function of living organisms.

Formulation of Cell Theory

Development of cell theory illustrates how scientific methodology operates. It involves observation, hypothesis, formulation of theory and its modification. Observations were started by Malthias Schleiden (1838), a German botanist who examined a large number of plant tissues. He found that all plant tissues were made of one or the other kind of cells. Therefore, he concluded that cells constitute the ultimate units of all plant tissues. Theodore Schwann (1838), a German Zoologist, studied different types of animal tissues including development of embryos. He found that animal cells lack a **cell wall**. Instead they are covered by a membrane. Otherwise cells of both plants and animals are similar. Schwann defined a cell as membrane enlocked, nucleus containing structure. He also proposed a **cell hypothesis** (Schwann, 1838)— *bodies of animals and plants are made of cells and their products.*

Schleiden and Schwann compared their findings, discussed Schwann's hypothesis and formulated the cell theory in their joint paper in 1839. The theory proposed that cells are the units of both structure and function of organisms. Rudolf Virchow (1855) observed that new cells develop by division of the pre-existing cells— *Omnis cellula e cellula* (theory of cell lineage or common ancestry). The finding gave cell theory its final shape. Louis Pasteur (1862) further proved that life originated from life. Soon Haeckel (1866) established that nucleus stores and transmits hereditary traits. Cell theory was modified accordingly.

Fundamental Features of Cell Theory

Five fundamental observations of the cell theory are:

1. All living organisms are composed of cells and their products.
2. Each cell is made of a small mass of protoplasm containing a nucleus in its inside and a plasma membrane with or without a cell wall on its outside.
3. All cells are basically alike in their chemistry and physiology.
4. Activities of an organism are the sum total of activities and interactions of its constituent cells.

Modern Cell Theory

It is also known as **cell doctrine** or **cell principle**. Modern cell theory states that

1. The bodies of all living beings are made up of cells and their products.
2. Cells are units of structure in the body of living organisms. Every cell is made up of a mass of protoplasm having a nucleus, organelles and a covering membrane.

3. Cells are units of function in living organisms, that is, the activities of an organism are the sum total of the activities of its cells.

4. While a cell can survive independently, its organelles cannot do so.

5. The cells belonging to diverse organisms and different regions of the same organism have a fundamental similarity in their structure, chemical composition and metabolism.

6. Life exists only in cells because all the activities of life are performed by cells.

7. Depending upon specific requirement, the cells get modified, *e.g.*, elongated in muscle and nerve cells, loss of nucleus in RBCs or cytoplasm in outer skin cells.

8. Growth of an organism involves the growth and multiplication of its cells.

9. Genetic information is stored and expressed inside cells.

10. Life passes from one generation to the next in the form of a living cell.

11. New cells arise from pre-existing cells through division. All new cells contain the same amount and degree of genetic information as contained in the parent cell.

12. All the present day cells/organisms have a common ancestry because they are derived from the first cell that evolved on the planet through continuous line of cell generations.

13. Basically the cells are totipotent (*i.e.*, a single cell can give rise to the whole organism) unless and until they have become extremely specialized.

14. No organism, organ or tissue can have activity that is absent in its cells.

Objections

(i) Viruses are acellular and do not have a cellular machinery. Even then they are considered to be organisms.

(ii) In some organisms, the body is not differentiated into cells though it may have numerous nuclei (coenocytes, *e.g., Rhizopus*).

(iii) Protozoans and many thallophytes have a uninucleate differentiated body (*e.g., Acetabularia*) which cannot be divided into cells. They are acellular.

(iv) Bacteria and cyanobacteria do not have nucleus and membrane bound organelles.

(v) RBCs and sieve tube cells continue to live without nucleus.

(vi) Protoplasm is replaced by nonliving materials in the surface cells of skin and cork.

(vii) Schleiden and Schwann did not know the mechanism of cell formation. Schwann believed cells to develop spontaneously like a crystal. Schleiden thought new cells to develop from cytoblast or nucleus.

Significance of Cell Theory. (i) There is a structural similarity in cells belonging to diverse groups of organisms. (ii) All the cells perform similar metabolic activities. (iii) Life exists only in the form of cells. (iv) Life passes from one generation to the next as cells. (v) All living beings are descendents of a primitive cell that developed on earth as the first eucaryote and prior to that as the first procaryote.

Surface : Volume Ratio

The factors which set the limit of cell size or volume are :

(i) Nucleo-cytoplasmic or kern-plasma ratio (ratio of nucleus to cytoplasm) which determines the range of control of metabolic activities by nucleus.

(ii) Ability of oxygen and other materials to reach every part of the cell.

(iii) Ability of waste products to pass to the outside.

(iv) Rate of metabolic activity.

(v) Ratio of surface area to the volume of the cell.

Metabolically active cells are usually smaller due to higher nucleocytoplasmic ratio and higher surface volume ratio. The former will allow the nucleus to have better control of metabolic activities while the latter will allow quicker exchange of materials between the cell and its outside environment.

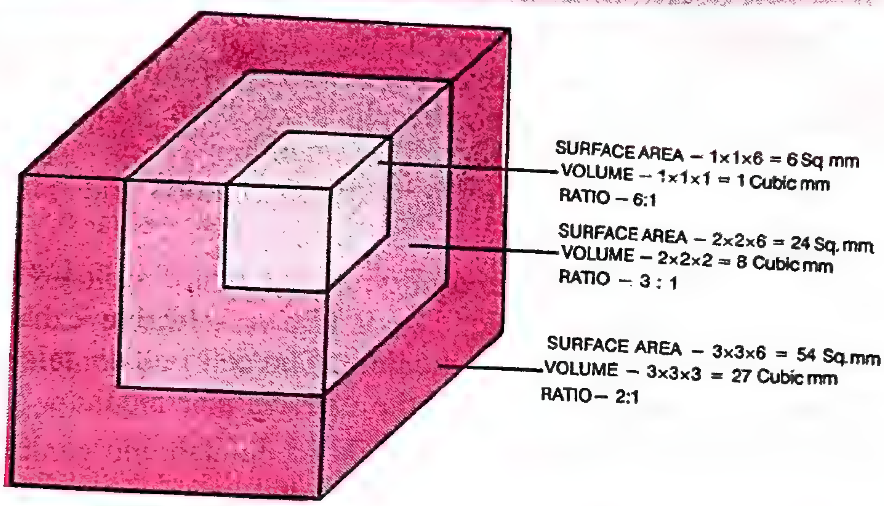


Fig. 8.3. Effect of size on surface area volume ratio.

Surface volume ratio decreases with the increase in cell size or volume as surface increases by the square of the size while volume increases by the cube of the size. Take three cubic cells which have the surface area of 6 mm^2 ($6 \times 1 \times 1$), 24 mm^2 ($6 \times 2 \times 2$) and 54 mm^2 ($6 \times 3 \times 3$) and a volume of 1 mm^3 ($1 \times 1 \times 1$), 8 mm^3 ($2 \times 2 \times 2$) and 27 mm^3 ($3 \times 3 \times 3$) respectively (Fig. 8.4). The surface to volume ratio in the three would be 6 : 1, 3 : 1 and 2 : 1. Therefore, larger cells have lesser surface volume ratio. They tend to become less efficient. All passive cells like eggs are, therefore, larger in size. All active cells are smaller. If larger cells are to remain active, they are either cylindrical in shape or possess several extensions of the cell membrane. **Microvilli** are one of such developments. They are found in all those cells which are active in absorption. Membrane infoldings also occur in **transfer cells** found in plants in the region of absorption or secretion of nutrients.

Types of Cells

A multicellular organism is composed of numerous cells. The cells are of three main types— **undifferentiated** (stem cells), **differentiated** (post-mitotic cells) and **dedifferentiated.**

(a) **Undifferentiated or Stem Cells.** They are unspecialised cells which usually possess the power of division, *e.g.*, stem apical meristem, root apical meristem, vascular cambium, cork cambium, stratum germinativum of skin, germinal epithelium, bone marrow, etc. Zygote is also an undifferentiated cell.

(b) **Differentiated or Post-mitotic Cells.** The cells are specialized to perform specific functions. Differentiation occurs in shape, size, structure and function through an orderly switching on and off of some particular genes of the cells by means of chemicals named as inducers and repressors. It leads to better organisation, division of labour and higher efficiency. Duplication of work is avoided.

(c) **Dedifferentiated Cells.** They are differentiated cells which revert to undifferentiated state to take over the function of division. The process by which they lose their specialization is called **dedifferentiation.** It involves reactivation of certain genes that prevent differentiation, allow limited growth and induce division. Cork cambium of plants is always produced through dedifferentiation. Dedifferentiation helps in healing of wounds, regeneration in animals, or vegetative propagation in plants. Cell culture experiments are based on this dedifferentiation of cells.

Compartmentalization for Cellular Life

Every cell behaves as a compartment because it is completely covered over by a membrane known as plasma membrane or plasmalemma. It may also possess some internal compartments in the form of membrane lined organelles like mitochondria, plastids, lysosomes, golgi bodies, nucleus, etc. Nonmembranous organelles occur in both procaryotic and eucaryotic cells, *e.g.*, ribosomes.

1. **Separation from Extracellular Medium.** Plasma membrane of the cell segregates its protoplasm from the extracellular medium. As a result, the protoplasm does not mix with the latter. It allows the cell to maintain its chemical pool, orderliness of structure and reactions in contrast to disorderly distribution and random interaction of molecules in the extra-cellular medium.

2. **Selective Permeability.** A cell is not a closed compartment. Its plasma membrane is selectively permeable, *i.e.*, it allows selective exchange of materials between the cell interior and extracellular medium. The cell is thus able to maintain its internal composition quite different from that of the extracellular medium.

3. **Accumulation.** Most cells accumulate inorganic nutrients against their concentration gradient. Sea weeds have iodine in concentration 2 million times the one present in sea water.

4. **Interconnections.** Compartmentalisation helps the cells to maintain their individuality. However, cells of a multicellular organism do not remain isolated. Cells of plant tissues are often connected with one another through cytoplasmic bridges called **plasmodesmata.** Junctions occur amongst animal cells.

5. **Recognition.** Cells are able to recognize one another due to presence of specific chemicals on their surface. Thus separated cells of different species of sponges would segregate species-wise if they are allowed to come together. Similar cells of a higher animal would segregate tissue-wise.

6. **Communication and Exchange**. Different cells of an organism communicate as well as exchange materials with one another.

7. **Intracellular Compartmentalisation**. Membrane lined cell organelles act as intracellular compartments. They allow the cells to separate diverse types of chemical reactions.

Cell— An Open System

An open system is the one which is separated from its surroundings by a boundary that allows transfer of materials and energy across it. Cell is an open system because it receives a number of materials including energy containing nutrients from outside. It liberates energy as heat and sends out excretions.

Cell Size

There is a wide variation in the size shaped and activities of cells. The smallest cells are those of *Mycoplasma*. They have a size of 0.1–0.5 μm. Bacteria measure 3–5 μm in length. Viruses are still smaller. They do not have a cellular structure. The smallest virus has a volume of 7.0×10^{-7} μm^3. The smallest mycoplasma has a volume of 1.0×10^{-3} μm^3 while the smallest bacterium possesses a volume of 2.0×10^{-2} μm^3. Unicellular eucaryotes have a size of 1–1000 μm. Sporozoite of *Plasmodium* is only 2 μm long. Cells of multicellular eucaryotes have a size range of 5–100 μm. Among multicellular organisms, human erythrocytes (RBC) are about 7 μm in diameter. Some lymphocytes are still smaller (6 μm). Cells of kidney, liver, skin and intestine are 20–30 μm in diameter. Muscle and nerve cells are

comparatively very large. A striated muscle cell can be 1– 40 mm long and 30–80 μm in thickness. Longest cells of human body are the nerve cells which may reach a length of 90cm.

Amongst plants, large cells occur in many algae. Internodal cells of *Chara* are 1–10 cm in length. *Acetabularia* (Fig. 8.4B), a unicellular alga, is upto 10 cm in length. It is differentiated into rhizoid, stalk and cap. Plant fibres are still longer— 4 cm in Cotton, 55 cm in Ramie, 30–90 cm in Jute and over a metre in Hemp.

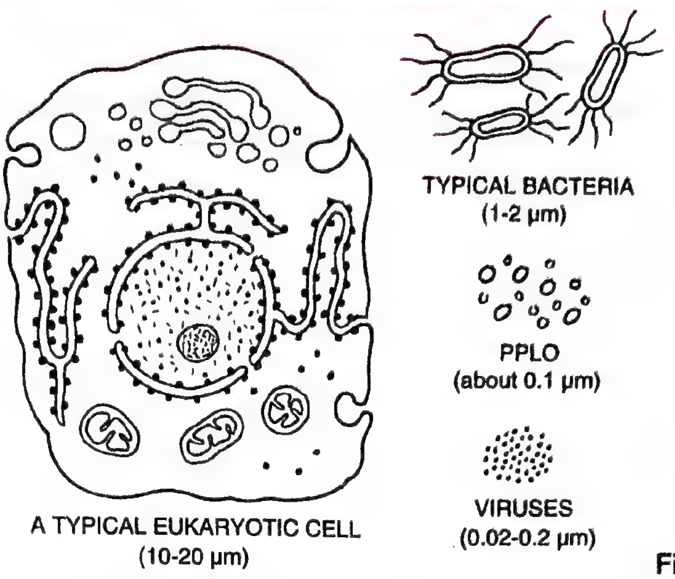


Fig. 8.4. A, Comparison of a typical eukaryotic cell with other unicellular organisms.

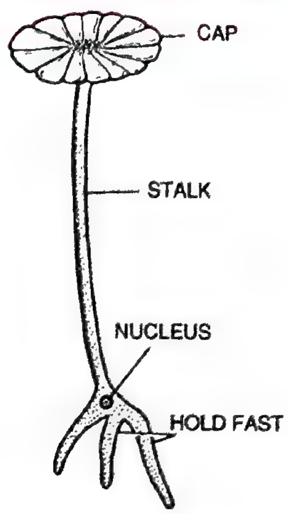


Fig. 8.4. B, *Acetabularia*, a single celled green alga, called umbrella plant.

In general, eggs are large sized cells because they store food for partial or complete development of the embryo. Human egg is slightly over 0.1* mm or 100 μm in diameter. It has a volume 1.4×10^6 μm^3 or 0.1 million times that of the human sperm (1.7×10^1 μm^3, table 8.1). Avian eggs are the largest. Hen egg is 60 × 45 mm with a volume of 5.0×10^{13} μm^3 while the egg of Ostrich is 170 × 150 mm with a volume of 1.1×10^{15} μm^3.

Table 8.1. Mean volumes of some cells and viruses

Cell Type	*Cell Volume (Cubic mm)*	*Cell Type*	*Cell Volume (Cubic mm)*
Ostrich Egg	1.1×10^{15}	Largest Bacterium	7.0×10^0
Hen Egg	5.0×10^{13}	Smallest Bacterium	2.0×10^{-2}
Human Egg	1.4×10^6	Mycoplasma	1.0×10^{-3}
Human sperm	1.7×10^1	Smallest Virus	7.0×10^{-7}

Shapes of Cells. The cells vary in their shapes. They may be disc like, polygonal, columnar, cuboid, amoeboid, thread like or irregular. The shape of cell is related to its position (flat in surface cells, polygonal in cortex) and function (*e.g.*, RBCs are biconcave to pass through capillaries and carry O_2 ; WBCs are irregular to do phagocytosis, nerve cells are long to conduct impulses, sperms have tail for motility etc. ; Fig. 8.5).

On the basis of organisation of DNA, the cells are of two types— **procaryotic** and **eucaryotic**. The organisms having procaryotic cells are called procaryotes. They are now-a-days placed in a superkingdom called **Procaryota**. Other organisms (having eucaryotic cells) are included in superkingdom **Eucaryota**. Procaryotic cells occur in bacteria, blue green algae, chlamydiae, Archaebacteria and Mycoplasma or PPLO.

* 1 centimetre or cm	=	10 millimetres or mm.	1 cm³ = 10³ mm³	1 mm³ = 10⁹ mm
1 millimetre or nm	=	1000 micrometres or mm	1 mm³ = 10³ nm³	1nm³ = 10³ Å³
1 micrometre or mm	=	1000 nanometres or nm		
1 nanometre or nm	=	10 angstroms or Å		

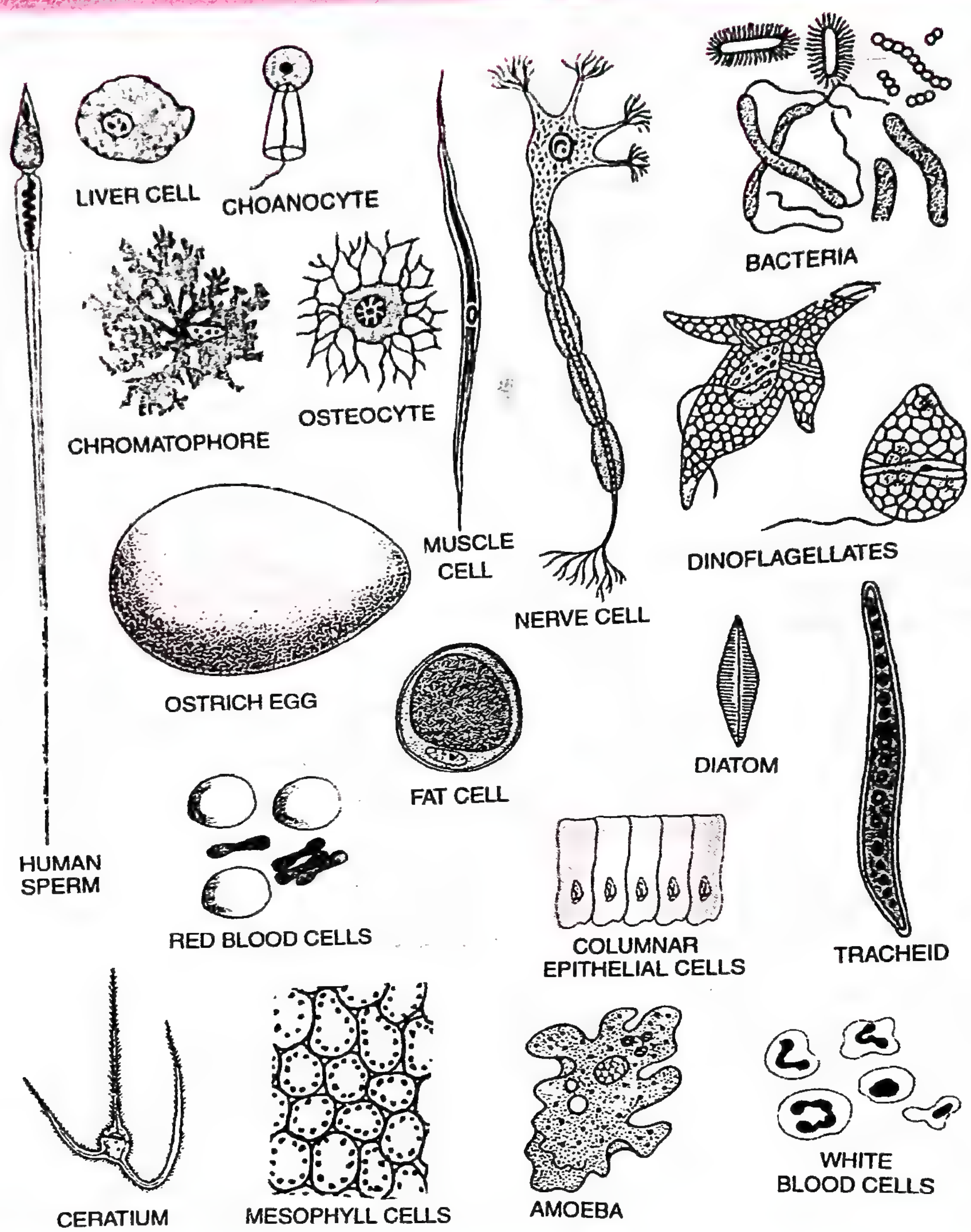


Fig. 8.5. Diagram showing different shapes of the cells.

Procaryotic Cells

Characteristics

1. **Nuclear Material.** DNA is naked and lies variously coiled in the cytoplasm. It is often called **genophore**, nuclear body or **nucleoid**. It is equivalent to a single naked chromosome and is, therefore, also called **prochromosome.** Many procaryotes also have additional small circular DNA entities called **plasmids**. Plasmids carry additional specific factors like nitrogen fixation, resistance, fertility, etc.

2. **Cell Wall.** It is present in bacteria and cyanobacteira. A cell wall is absent in mycoplasma or PPLO.

3. **Flagella and Fimbriae.** Flagella are present in some bacteria only (Fig. 8.6). The bacterial flagella are single-stranded as compared to 11-stranded flagella of eucaryotes. In some bacteria, nonmotile appendages called **pili** or **fimbriae** also occur. They take part in attachment (*e.g., Neisseria gonorrhoeae*) and conjugation (*e.g., Escherichia coli*).

4. **Photosynthetic Thylakoids.** Blue - green algae and some bacteria are photoautotrophic. Their photosynthetic thylakoids lie freely in the cytoplasm. They are not organised into chloroplasts.

5. **Membrane-lined Cell Organelles.** The procaryotic (= prokaryotic) cells lack mitochondria, endoplasmic reticulum, golgi apparatus, lysosomes, microtubules, microfilaments and centrioles.

6. **Vacuoles.** Typical vacuoles are doubtful. Instead complex gas vacuoles are found.

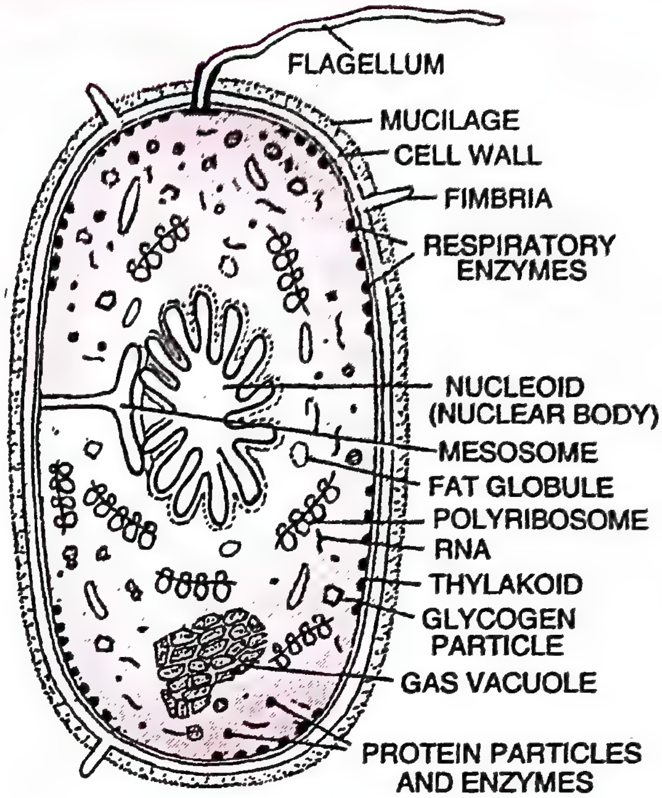


Fig. 8.6. Ultrastructure of a bacterial cell.

7. **Ribosomes.** Ribosomes are 70S as compared to 80S. Similar 70S ribosomes occur inside chloroplasts and mitochondria of eucaryotes.

8. **One-Envelope System.** In procaryotic cells, membrane bound cell organelles are absent so that there is a single membrane that surrounds the cell. Hence, procaryotes have a single membrane or **one-envelope system**. Genetic material lies freely in the cytoplasm. Eucaryotes have a **two-envelope system,** outer plasma membrane contained cytoplasm and inner nuclear envelope contained genetic material.

9. **DNA Content.** It is low.

10. **Transcription and Translation.** Both occur in the cytoplasm.

11. **Respiratory Enzymes.** They usually lie in contact with cell membrane.

Structure of a Bacterial Cell

It is a primitive type of cell in which genetic material is not organised in the form of nucleus but instead lies freely in a naked super-coiled state in the cytoplasm whence it is known as **prochromosome** or **nucleiod.** Prokaryotic (= procaryotic) cells are known for their rapid multiplication. The average size is 2.0–2.6 μm long and 1.1–1.5 μm wide.

In shape, bacterial cells are of many types (Fig. 8.7). Mycelial form is found in actinomycetes.

1. **Coccus** (Gk. *kokkos*– berry). Coccus bacteria are spherical or ovoid in outline. Depending upon their grouping they are called (i) **Monococcus** (occurring singly), (ii) **Diplo-**

coccus (in twos), (iii) **Tetracoccus** (in tetrads), (iv) **Streptococcus** (in chains), (v) **Staphylococcus** (irregular grape-like clusters) and (vi) **Sarcina** (3-dimensional geometrical forms).

2. **Bacillus** (L. *bacillus*– small rod). The bacterium is straight and cylindrical like a rod with ends being flat, rounded or cigar shaped. It has three special types : (i) **Diplobacillus** (in twos), (ii) **Palisade Bacillus** (like a stack) and (iii) **Streptobacillus** (in chains).

3. **Spirillum** (L. *spira*– coil). The bacterium is coiled like a cork-screw, *e.g., Spirillum, Spirochaete*. Aggregation does not occur.

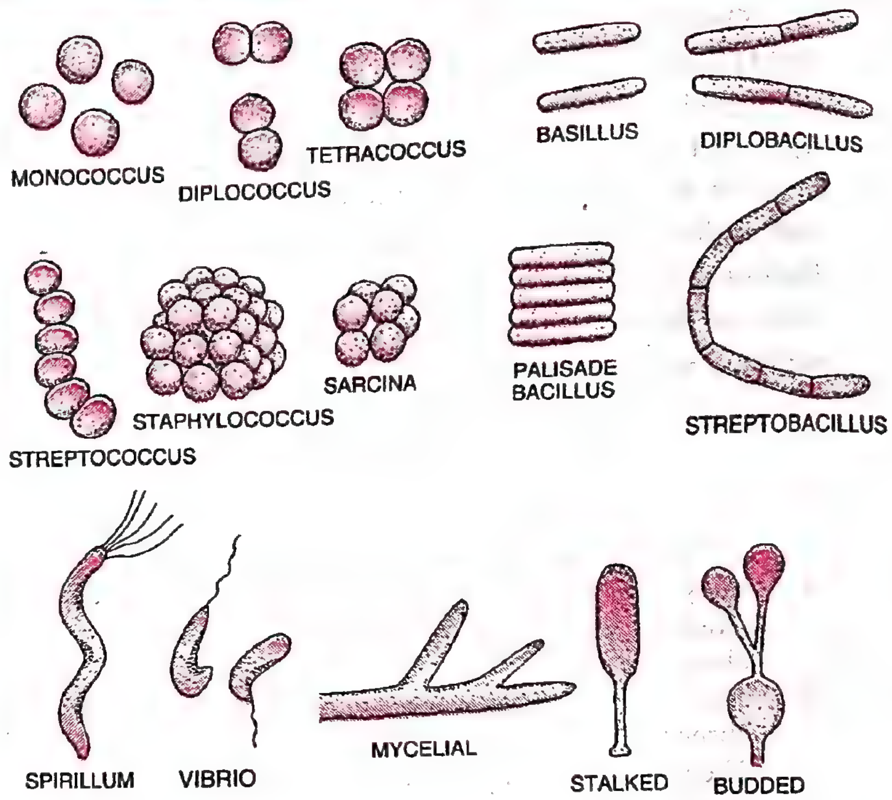


Fig. 8.7. Various forms of bacteria.

4. **Vibrio**. The body of the bacterium is like a comma, curved rod or single turn of the spiral *e.g., Vibrio cholerae*. Like spirillum bacteria, the vibrio forms live singly.

5. **Stalked**. The bacterium possesses a stalk, *e.g., Caulobacter*.

6. **Budding**. The bacterium is swollen at places, *e.g., Rhodomicrobium*.

Flagellation. Depending upon the presence or absence of flagella, bacteria are grouped into flagellate and nonflagellate types. The various forms of flagellation (Fig. 8.8) are as follows :

(a) **Atrichous.** Flagella absent.

(b) **Monotrichous.** A single flagellum occurs at or near one end of bacterium.

(c) **Amphitrichous**. A flagellum at each of the two ends.

(d) **Lophotrichous**. A group or tuft of flagella is found only at one end.

(e) **Cephalotrichous**. A tuft or group of flagella occurs at each of the two ends or poles. The term **amphitrichous** is also used for this condition.

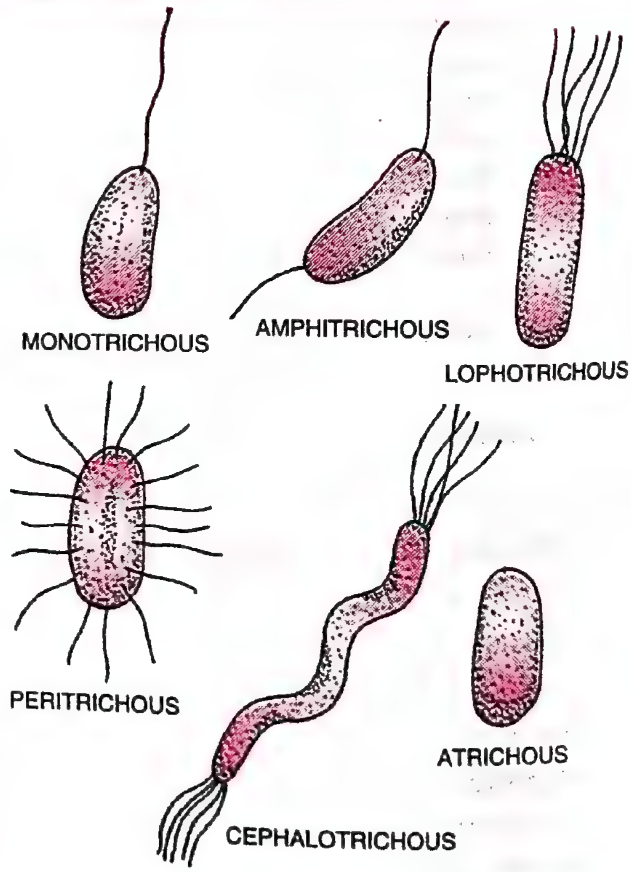


Fig. 8.8. Flagellation types in bacteria.

(f) **Peritrichous**. A number of flagella are distributed all over the surface.

Gram Positive and Gram Negative Bacteria

The grouping is based on the reaction of bacteria to **Gram's stain** (Christian Gram, 1884). Bacteria are stained first with weakly alkaline solution of crystal violet or gentian violet, when all of them pick up blue colour. They are then treated with 0.5% iodine solution followed by washing with water and then absolute alcohol or acetone. Bacteria which retain blue or purple colour are known as **Gram (+) bacteria** (*e.g., Bacillus subtilis*). Bacteria which do not retain any stain and become colourless are termed as **Gram (–) bacteria** (*e.g., Escherichia coli*). (Gram–ve bacteria are commonly stained with safranin). Washing of the stain in Gram –ve bacteria is due to high lipid content of cell wall which gets dissolved in organic solvents like acetone.

Differences between Gram +*ve* and Gram-*ve* Bacteria

Gram +ve Bacteria	*Gram–ve Bacteria*
1. They remain coloured blue or purple with Gram stain even after washing with absolute alcohol or acetone.	1. The bacteria do not retain the stain when washed with absolute alcohol.
2. The wall is single layered. Outer membrane is absent.	2. The wall is two layered. Outer membrane is present.
3. The thickness of the wall is 20-80 nm.	3. It is 8-12 nm.
4. The lipid content of the wall is quite low.	4. The lipid content of the wall is 20-30%.
5. The wall is straight.	5. The wall is wavy and comes in contact with plasmalemma only at a few places.
6. Murein or mucopeptide content is 70-80%.	6. It is 10-20%.
7. Basal body of the flagellum has two rings of swellings.	7. Four rings of swellings occur in the basal body.
8. Mesosomes are more prominent.	8. Mesosomes are less prominent.
9. The bacteria are more susceptible to antibiotics.	9. They are more resistant to antibiotics.
10. Fewer pathogenic bacteria belong to Gram +ve group.	10. Most of the pathogenic bacteria are Gram –ve.
11. Porins are absent.	11. Porins or hydrophilic channels occur in outer membrane of cell wall.
12. Cell wall contains teichoic acids.	12. Teichoic acids are absent.

Components of Bacterial Cell

A bacterial cell (Fig. 8.9) consists of a cell envelope, cytoplasm, nucleiod, plasmids, inclusion bodies, flagella, pili and fimbriae.

1. **Cell Envelope.** It is the outer covering of protoplasm of bacterial cell. Cell envelope consists of 3 components— glycocalyx, cell wall and cell membrane.

(i) **Glycocalyx.** It lies outside the cell wall. Glycocalyx consists of two parts, inner S-layer and outer mucilage. S-layer is mostly made of polypeptides rich in acidic amino acids. It protects the bacteria cell wall dissolving lysozyme and other harmful chemicals. Mucilage is carbohydrate rich which when thick is called **capsule.** Glycocalyx gives sticky character to the cell. It is not absolutely essential for survival of bacteria. However, it has several secondary functions. (a) Prevention of desiccation. (b) Protection from phagocytes. (c) Protection from toxic chemicals and drugs. (d) Protection from viruses. (e) Attachment. (f) Immunogenicity (g) Virulence.

A number of bacteria also produce extracellular **cellulose,** *e.g., Azotobacter, Salmonella.*

(ii) **Cell Wall.** It is rigid solid covering which provides shape and structural support to the cell. Cell wall lies between plasma membrane and glycocalyx. **Periplasmic space** occurs between plasma membrane and cell wall. Cell wall protects the bacterial cells against bursting in hypotonic solution. Wall is 20–80 nm thick in Gram positive bacteria. It is single layered and smooth. In Gram negative bacteria, wall is 8–12 nm thick, complex, wavy and two layered. The outer layer is also called **outer membrane**. It consists of lipopolysaccharides, lipids and proteins. The outer membrane has hydrophilic channels of 16-stranded β-barrel proteins called **porins**. The single layered cell wall of Gram positive bacteria and inner wall layer of Gram negative is made up of pepidoglycan, proteins, non-cellulosic carbohydrates, lipids, amino acids, etc. Peptidoglycan forms the structural network of the cell wall. It is also known as **murein** or **mucopeptide**. Peptidoglycan consists of long glycan strands formed of repeating units of N-acetyl glucosamine (NAG) and N-acetyl muranic acid (NAM). They are cross linked by small peptide chains. Peptidoglycan constitutes 70–80% of wall in Gram positive bacteria. Lipid content is little. 10–20% of wall in Gram negative bacteria is formed of peptidoglycan. Lipid content is 20–30%. Amino acid present in the wall is diaminopimelic acid or lysine. In Gram positive bacteria, the wall contains **teichoic acids** that form receptor sites and surface antigens. In *Mycobacterium* and *Nocardia*, the wall contains long chain fatty acids called **mycolic acids.**

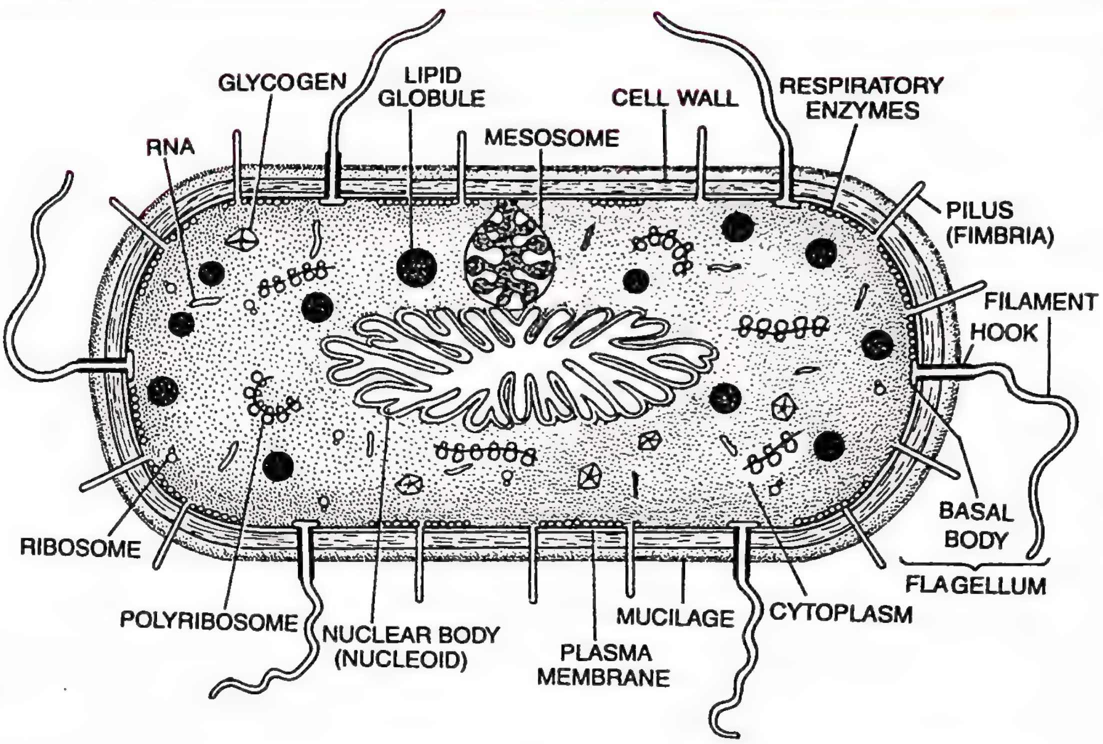


Fig. 8.9. Cell structure under electron microscope (Plasmid and volutin granules not shown).

(iii) **Plasma Membrane.** It is selectively permeable covering of the cytoplasm that forms the innermost component of cell envelope. Bacterial plasma membrane or plasmalemma has a structure similar to that of a typical membrane. It is made of a phospholipid bilayer with proteins of various types (extrinsic, integral, transmembrane). It holds receptor molecules for detection and responding to different chemicals of the surroundings. Bacterial membrane is metabolically active as it takes part in respiration, synthesis of lipids and cell wall components.

2. **Cytoplasm.** It is crystallo-colloidal complex that forms the protoplasm excluding its nucleoid. Cytoplasm is granular due to presence of a large number of ribosomes. Membrane bound cell organelles as found in eukaryotes are absent. However, all biochemical pathways are found in prokaryotic cells. Cytoplasmic streaming is absent. Sap vacuoles are absent. Instead gas vacuoles are present. Various structures present in cytoplasm are as follows :

(i) **Mesosome** (Fitz James 1960). It is a characteristic circular to villiform specialisation of cell membrane of bacteria that develops as an ingrowth from the plasma membrane. It consists of vesicles, tubules and lamellae. Mesosme is of two types, septal and lateral. **Septal mesosome** connects nucleoid with plasma membrane. It takes part in replication of nucleoid by providing points of attachment to the replicated ones. Septal mesosome is also believed to help in septum formation. At the time of cell division, plasma membrane grows in the region where the septal mesosme is present so that most probably it provides membranes for rapid elongation. **Lateral mesosme** is not connected with nucleoid. It contains respiratory enzymes and is, therefore, often called **chondrioid**. It is beleived to be equal to mitochondrion of eukaryotes. However, respiratory enzymes are also present over the plasma membrane.

(ii) **Ribosomes.** They are small membraneless, submicroscopic ribonucleoprotein entities having a size of 20 nm × 14–15 nm. Ribosomes are of two types, fixed and free. **Fixed ribosomes** are attached to the plasma membrane. **Free ribosomes** occur free in the cytoplasmic matrix. The ribosomes are 70S in nature. (Here *S* denotes sedimentation coefficient or Svedberg number). Each ribosome has two subunits, larger 50S and smaller 30S. Ribosomes take part in protein synthesis. Free or matrix ribosomes synthesize proteins for intracellular use while fixed ribosomes synthesize proteins for transport to outside. Ribosomes generally occur in helical groups called **polyribosomes** or **polysomes**. In each polysome 4–8 ribosomes are attached to a single strand of messenger or mRNA. It is a mechanism to synthesise several copies of the same protein.

(iii) **Chromatophores.** They are internal membrane systems of photosynthetic forms which possess photosynthetic pigments. In purple bacteria the membranes are typical while in green bacteria they are nonunit, nonlipid and proteinaceous. Chromatophores of green bacteria are called **chlorosomes**. Photosynthetic pigments are bacteriochlorophyll, bacteriophaeophytin (bacterio-viridin) and carotenoids.

3. **Nucleoid.** It represents the genetic material of prokaryotes. Several alternative names have been given to nucleoid— **genophore, prochromosome, incipient nucleus** and **chromoneme.** Nucleoid consists of a single circular strand of DNA duplex which is supercoiled with the help of RNA and polyamines to form a nearly oval or spherical complex. The folding is 250-700 times. Polyamines or nucleoid proteins are different from histone proteins. DNA of prokaryotes is considered **naked** because of its non-association with histone proteins and absence of nuclear envelope around it. In *E.coli*, nucleoid has 1100 μm long DNA duplex with 4.6×10^6 base pairs. Nucleoid is embedded freely in the cytoplasm. A cell can have 2 or more nucleoids but all are replicated copies of same nucleoid. It is equivalent to a **single chromosome** of eukaryotes because nucleoid consists of a single DNA double strand. Nucleoid may be directly attached to the plasma membrane or through the mesosome.

4. **Plasmids.** They are self replicating, extra chromosomal segments of double stranded, circular, naked DNA. Plasmids provide unique phenotypic characters to bacteria. They are independent of main nucleoid. Some of them contain important genes like fertility factor, nif genes, resistance factors and colicinogenic factors. Plamsids which can get associated temporarily with nucleoid are known as **episomes**. Plasmids are used as vectors in genetic engineering.

5. **Inclusion Bodies**. They are non-living structures present in the cytoplasm. The inclusion bodies may occur freely inside the cytoplasm (*e.g.*, cyanophycean granules, volutin or phosphate granules, glycogen granules) or covered by 2-4 nm thick non-lipid, non-unit protein membrane (*e.g.*, gas vacuoles, carboxysomes, sulphur granules, PHB granules). On the basis of their nature, the inclusion bodies are of 3 types— gas vacuoles, inorganic inclusions and food reserve.

(i) **Gas Vacuoles**. They are gas storing vacuoles found in cyanobacteria, purple and green bacteria and a few other planktonic forms. A gas vacuole is without any covering of its own. It consists of a variable number of hexagonal, hollow and cylindrical **gas vesicles**. Each gas vesicle is surrounded by a single non-unit, non-lipid protein membrane having ribs or folds. The membrane is impermeable to water but is permeable to atmospheric gases. Gas vacuoles protect the bacteria from harmful radiations. They also constitute buoyancy regulation mechanism for their proper positioning in water during daytime for photosynthesis.

(ii) **Inorganic Inclusions.** Several types of inorganic granules occur in bacteria. They include volutin granules, sulphur granules, iron granules, magnetite granules, etc. Because of the ability to pick up different colours with basic dyes, they are called **metachromatic granules**. Two common types of inorganic granules are volutin granules and sulphur granules. Volutin granules are polymetaphosphates which function as storage reserve of phosphate. Sulphur granules occur in bacteria living in sulphur rich medium like the one which pick up hydrogen sulphide for obtaining reducing power in photosynthesis. Iron granules are similarly found in those bacteria which metabolise iron compounds for obtaining energy. *Aquaspirillum magnetotacticum* contains **magnetosomes,** which are vesicles having magnetite. The granules help the bacteria to orientate themselves along geomagnetic lines.

(iii) **Food Reserve**. Blue green algae have **cyanophycean starch** or α–granules, β-granules or **lipid globules** and **cyanophycin** or protein granules. In bacteria, starch is replaced by glycogen. Neutral fats are absent. Instead **poly-beta-hydroxy-butyrate** or PBH granules are present. A biodegradable plastic can be prepared from PBH. Protein granules are present. Carboxysomes occur in photosynthetic forms.

6. **Flagella** (Fig. 8.10). Bacterial flagella are unistranded, equivalent to a single microtubular fibre. It is about 20 nm (0.02 μm) in diameter and 1-7μm in length. Bacterial flagellum is made up of 3 parts— **basal body**, **hook** and **filament**. Basal body is like a rod. It is inserted in the cell envelope. The basal body bears ring-like swellings in the region of plasma membrane and cell wall. There are two pairs of rings (L and P ring in cell wall and S and M rings

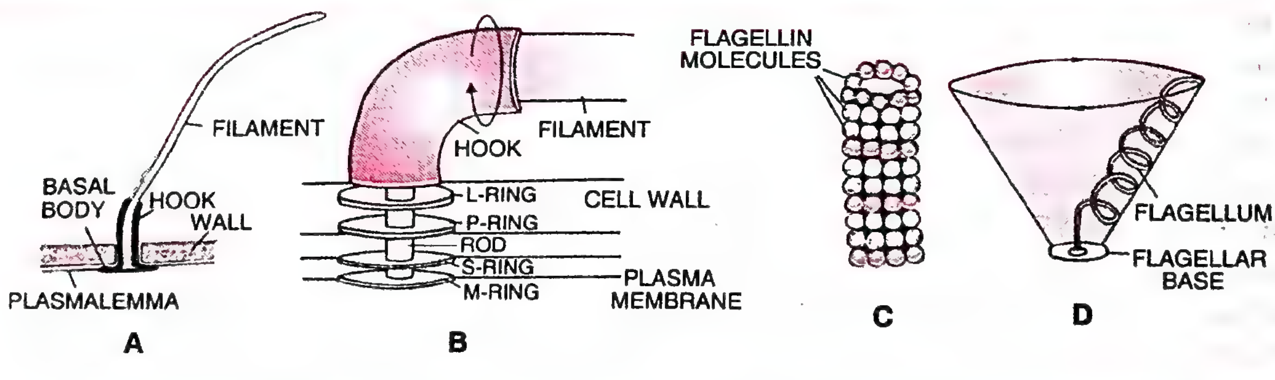


Fig. 8.10. Bacterial flagellum. A, parts of flagellum. B, Lower region of flagellum of a Gram negative bacterium. C, filament canal with flagellin molecules. D, mode of flagellar movement.

embedded in cell membrane) in Gram negative bacteria and only a single pair of rings (S and M rings embedded in cell membrane) in Gram positive bacteria (Fig. 8.10 B). Hook is curved tubular structure which connects the filament with the basal body. It is the thickest part of flagellum. Filament part is long tubular structure which causes turbulence in the liquid medium. It is made up of protein called **flagellin.** Protein molecules are globular. They are arranged in 3–11 spiral rows (Fig. 8.10 C). A proton pump or **stator** and a molecular motor or **rotator** occur at the bottom of basal body. The bacterial flagella perform rotation type movement (Lowy and Spencer 1968) that brings about backward pushing of the water. It results in the bacterium moving forward.

7. **Pili and Fimbriae.** The two terms have been used interchangeably for bacterial appendages which are not involved in locomotion. Actually, pili (singular-pilus) are longer, fewer and thicker tubular outgrowths which develop in response to F^+ or fertility factor in Gram negative bacteria. They are made up of protein **pilin.** A donor bacterial cell having fertility factor develops 1–4 pili. Being long (18–20 μm) they are helpful in attaching to recipient cell and forming conjugation tube.

Fimbriae are small bristle-like protein fibres sprouting from cell surface in large number. There are 300–400 of them per cell. Diameter is 3–10 nm while length is 0.5–1.5 μm. Fimbriae are involved in attaching bacteria to solid surfaces (*e.g.,* rock in water body) or host tissues (*e.g.,* urinary tract in *Neisseria gonorrhoeae*). Some fimbriae cause agglutination of RBC. They also help in mutual clinging of bacteria.

Differences between Pili and Fimbriae

Pili	*Fimbriae*
1. They occur only in Gram negative bacteria.	1. Fimbriae are found in both Gram +ve and Gram –ve bacteria.
2. The number is 1-4 per cell.	2. The number is 300-400 per cell.
3. Pili are longer and broader.	3. Fimbriae are shorter and narrow.
4. They help in conjugation.	4. They take part in adhesion.
5. Formation of pili is controlled by F^+ or fertility factor.	5. Formation of fimbriae is controlled by a nucleoid gene.
6. They are tubular structures.	6. They are bristle-like solid structures.

Eucaryotic Cells

A eucaryotic cell is the one which has an organised nucleus and several membrane covered cell organelles. Except monera, the cells of all other kingdoms have eukaryotic organisation. Cell wall is present in cells of plants, fungi and some protists. It is absent in animal cells and some protists. Wall-less cells are generally irregular. Otherwise, internal structure of all cells is somewaht similar. *A cell is an organised mass of protoplasm surrounded by a protective and selectively permeable membrane*. Protoplasm of a cell is called **protoplast** (Hanstein, 1880). It is made up of cytoplasm, nucleus and vacuoles. Initially, cytoplasm was thought to have simple organisation. Electron microscope has shown that cytoplasm has a complex organisation formed of cytoplasmic matrix and cell organelles. There are cytoskeletal structures which not only provide movement to cytoplasm but also other locomotory activities. Genetic material or DNA is organised into chromosomes and chromatin. Plant cells possess cell wall, plastids and large central vacuole. They are absent in animal cells. Animal cells possess centrioles that are absent in plant cells.

An Over view of Eucaryotic Cell

A plant cell consists of **cell wall** and **protoplast**. Cell wall is absent in animal cells. Protoplast denotes the whole of protoplasm present in a cell. It is differentiated into **plasma membrane** (= plasmalemma or cell membrane), **cytoplasm, nucleus** and **vacuoles.** Cytoplasm is distinguishable into **cytoplasmic matrix** and **organelles**. Cytoplasmic matrix is also called **hyaloplasm.** It is a polyphasic colloidal system which exists in two states, sol and gel. The gel form usually occurs near the plasma membrane. This region is sometimes called **ectoplast** in contrast to sol region known as **endoplast.** Ectoplast is firmer. It is quite conspicuous on the free sides of the cells. In protozoans, ectoplast is prominent on all sides. Cytoplasmic matrix is generally in perpetual motion. The phenomenon is called **cyclosis,** cytoplasmic or protoplasmic streaming. Cytoplasmic matrix occupies the volume of the cells. It is the major arena of cellular activities that keep a cell in the living state.

In the cytoplasmic matrix are embedded a large number of **cell organelles** or organised protoplasmic subunits having specific functions. They are endoplasmic reticulum, plastids, mitochondria, ribosomes, Golgi bodies, centrioles (central apparatus, centrosome), lysosomes, sphaerosomes, peroxisomes, glyoxysomes, vacuoles, microtubules, microfilaments, etc. Some of them have membrane covering while others are without the same. Doubling membrane covering occurs around plastids and mitochondria. Single membrane covering is found over endoplasmic reticulum, Golgi apparatus, lysosomes, sphaerosomes, peroxisomes, glyoxysomes and vacuole. Organelles without a membrane covering are ribosomes, microtubules, microfilaments and centrosomes or centrioles (in animal cells). Ribosomes are found in both prokaryotes and eukaryotes. In eukaryote cells they occur in cytoplasmic matrix, over rough endoplasmic reticulum, inside plastids (found only in plants and some protists and mitochondria).

Cell inclusions include starch grains, glycogen granules, fat droplets, aleurone grains, excretory or secretory products and crystals.

Nucleus is also embedded in the cytoplasmic matrix. It is surrounded by a double membrane envelope and contains nucleoplasm, one or more nucleoli and chromatin having DNA. DNA is the genetic material.

Functions of Cell Parts

1. **Cell Wall** — Shape, rigidity and protection to cell.

2. **Plasma membrane** — Regulation of substances leaving or entering a cell.

3. **Cytoplasm.** (a) *Endoplasmic Reticulum* — Cytoskeleton, channelisation, synthesis of fats, steroids, proteins, formation of vacuoles and vesicles. (b) *Ribosomes*— Protein synthesis. (c) *Mitochondria*— Krebs cycle, amino acid synthesis, fatty acid synthesis. (d) *Chloroplasts*— Photosynthesis. (e) *Amyloplasts*— Storage of starch. (f) *Golgi Apparatus*— Storage, secretion, excretion, wall synthesis, some chemical transformations, membrane transformation, lysosome formation. (g) *Centrioles*— Formation of astral poles, flagella. (h) *Lysosomes*— Separation and storage of hydrolytic (digestive) enzymes, digestion, autophagy. (i) *Sphaerosomes*— Metabolism, storage and synthesis of fats. (j) *Glyoxysomes*— Glyoxylate cycle, conversion of fat to carbohydrates. (k) *Peroxisomes*— Photorespiration, peroxide metabolism. (l) *Microtubules*— Cytoskeleton, formation of spindle and flagella. (m) *Microfilaments*— Holding of membrane proteins, controlling cleavage and cyclosis. (n) *Vacuole*— Osmotic pressure, storage.

4. **Nucleus** — Carrier of hereditary information, control of cell metabolism, cell differentiation, synthesis of DNA and RNA, formation of ribosomes, control of reproduction.

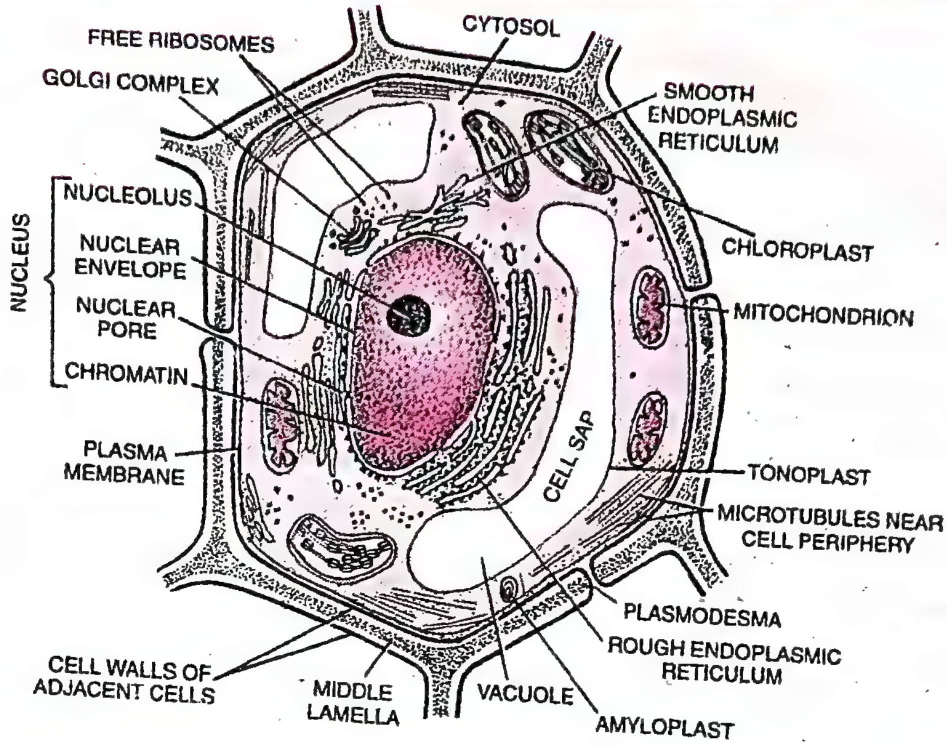


Fig. 8.11. A generalised ultra structure of an eucaryotic plant cell.

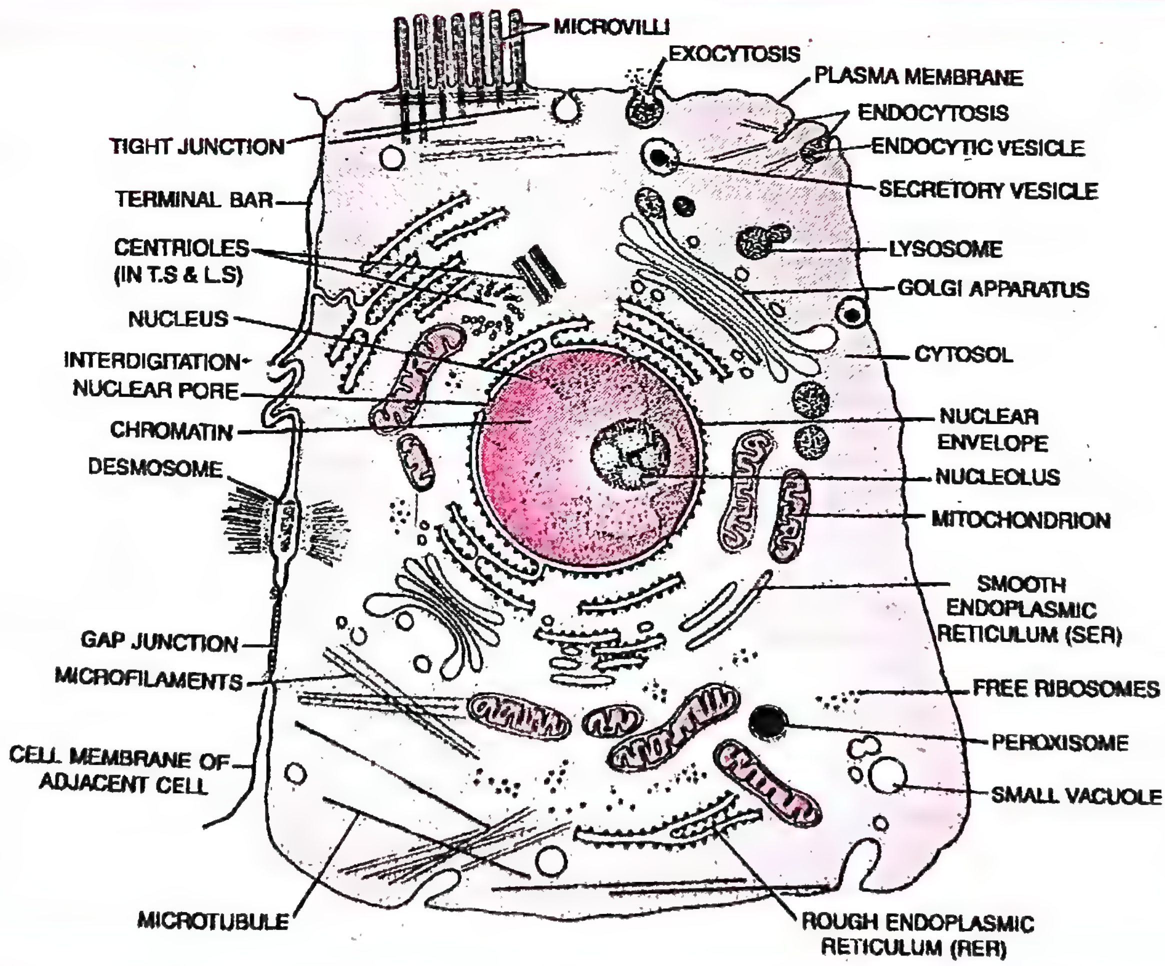


Fig. 8.12. A generalised ultrastructure of an eucaryotic animal cell.

Differences between Procaryotic and Eucaryotic Cells

Procaryotic Cell	*Eucaryotic Cell*
1. The cell size is usually small (0.1— 5.0 μm).	1. The cell size is comparatively larger (5—100μm).
2. A procaryotic cell has one envelope organisation.	2. A eucaryotic cell has two envelope organisation.
3. The flagella, if present, are single stranded, and without differentiation of axoneme and sheath.	3. The flagella, if present, are 11-stranded, with differentiation of axoneme and sheath.
4. An organized nucleus is absent. Instead a nucleoid is found.	4. An organized nucleus is found. It is differentiated into nuclear envelope, chromatin, one or more nucleoli and nucleoplasm.
5. Cell wall, if present, possesses muramic acid.	5. Cell wall, if present, without muramic acid.
6. DNA is naked, that is, without histones.	6. Nuclear DNA is associated with histones.
7. DNA is usually circular.	7. Nuclear DNA is linear. Extra nuclear DNA is commonly circular.
8. The ratio of A + T/G + C is low, < 1.	8. The ratio of A + T/G + C is high, > 1.
9. DNA lies freely in the cytoplasm. It is not associated with any organelle.	9. Most of the cell DNA lies in the nucleus. A small quantity is also found in the plastids and mitochondria.
10. The amount of DNA does not change as there are no haploid and diploid stages.	10. The amount of DNA shows a regular alternation between diploid and haploid stages.
11. Transcription and translation occur in the cytoplasm.	11. Transcription occurs in the nucleus while translation takes place in the cytoplasm.
12. Protein synthesis occurs only in cytoplasm.	12. Protein synthesis takes place in cytoplasm, mitochondria and plastids.
13. Respiratory enzymes are associated with plasma membrane.	13. Respiratory enzymes are present in both cytoplasm as well as mitochondria.
14. Endocytosis and exocytosis are absent.	14. They are quite common.
15. Cytoplasm does not show cyclosis.	15. Cytoplasm usually shows cyclosis.
16. Ribosomes are of 70 S type.	16. Ribosomes are of 80S type. 70S ribosomes however, occur in plastids and mitochondria.
17. Membrane bound organelles like ER, mitochondria, Golgi apparatus, centrioles, lysosomes and other microbodies are absent.	17. Mitochondria, ER, Golgi apparatus and microbodies including lysosomes, centrioles are present in cells of organisms in which motile stage is present in the life cycle.
18. True or sap vacuoles are usually absent. Instead, gas vacuoles, may be found.	18. True or sap vacuoles are commonly found.
19. Microtubules and microfilaments are commonly absent.	19. Microtubules and microfilaments are important constituents of eucaryotic cells.
20. Thylakoids, if present, lie freely in cytoplasm.	20. Thylakoids, if present, are grouped inside the chloroplasts.
21. Gametes are not formed, since sexual reproduction and meiosis are absent.	21. Gametes are formed either directly or through meiosis, as sexual reproduction is found in the life cycle.
22. A spindle apparatus is not formed during division.	22. A spindle apparatus is produced during nuclear division.
23. Nucleoid is equivalent to a single chromosome or prochromosome.	23. Nucleus contains more than one chromosomes.

Differences between Plant and Animal Cells

Plant Cell	*Animal Cell*
1. A plant cell has a rigid wall on the outside.	1. A cell wall is absent.
2. It has a definite form.	2. A definite form is less common.
3. It is usually larger in size.	3. An animal cell is comparatively smaller in size.
4. It cannot change its shape.	4. An animal cell can often change its shape.
5. It cannot change its pisition or move about.	5. Many animal cells can change position or move about.
6. Plastids are found in plant cells.	6. Plastids are usually absent.
7. Plant cells exposed to sunlight possess chlorophyll containing plastids called chloroplasts.	7. Chlorophyll is absent.
8. A mature cell has a large central vacuole.	8. An animal cell may have many small vacuoles.
9. Nucleus lies on one side in the peripheral cytoplasm due to central vacuole.	9. Nucleus usually lies in the centre.
10. Nucleus is elliptical.	10. Nucleus is rounded.
11. Mitochondria are comparatively fewer.	11. Mitochondria are generally numerous.
12. Plant cells do not burst if placed in hypotonic solution due to the presence of cell wall.	12. Animal cells usually burst if placed in hypotonic solution unless and until they possess contractile vacuoles.
13. Centrioles are usually absent.	13. Centrioles are found in animal cells.
14. Spindle apparatus nuclear division is anastral.	14. Spindle is amphiastral.
15. Golgi apparatus consists of a number of distinct or unconnected units called dictyosomes.	15. Golgi apparatus is either localised or consists of a well connected single complex.
16. The cell cannot take part in phagocytosis.	16. It can ingest materials through phagocytosis.
17. Lysosomes are rare. Their activity is performed by specialised vacuoles.	17. Typical lysosomes occur in animal cells.
18. Glyoxysomes may be present.	18. They are absent.
19. A plant cell produces all the materials needed by it.	19. An animal cell cannot synthesise certain amino acids, fatty acids, vitamins and coenzymes needed by it.
20. Crystals of inorganic substances occur inside the cells.	20. Crystals usually do not occur in animal cells.
21. Reserve food is generally starch and fat.	21. Reserve food is usually glycogen and fat.
22. A tissue fluid does not bathe the ells.	22. A tissue fluid having NaCl bathes cells.
23. Adjacent cells may be connected through plasmodesmata.	23. Adjacent cells are connected through a number of cell junctions.
24. Cytokinesis occurs by cell plate.	24. Cytokinesis takes place by cleavage.

The various cell components of eukaryotic cells are described below to understand their structure and functions.

I. Cell Wall

It is the outer rigid protective supportive and semitransparent covering of plant cells, fungi and some protists. Cell wall was first seen in cork cells by Hooke in 1665. Its thickness varies in different types of cells from 0.1 μm to 10 μm. Cell wall is a non-living extracellular secretion or matrix of the cell which is closely appressed to it. It is, however, metabolically active and is capable of growth. Cell wall performs a number of functions :

(i) Protects the protoplasm against mechanical injury. (ii) Protects the cell from attack of pathogens. (iii) Provides rigidity and shape to the cell. (iv) Counteracts osmotic pressure. (v) Gives strength to the land plants to withstand gravitational forces. (vi) By its growth the wall helps in cell expansion. (vii) Pits present in the wall help produce a protoplasmic continuum or **symplast** amongst cells. (viii) Walls prevent bursting of plant cells by inhibiting excessive endosmosis. (ix) Wall has some enzymatic activity connected with metabolism. (x) In many cases, wall takes part in offence and defence. (xi) Cutin and suberin of the cell wall reduce the loss of water through transpiration. (xii) Walls of sieve tubes, tracheids and vessels are specialised for long distance transport. (xiii) Some seeds store food in the form of hemicellulose in cell wall.

Cell wall of plants consists of cellulose, hemicellulose, pectin and protein. Besides cellulose, the algal cell walls contain galactans, mannans and calcium carbonate.

Chemical Composition of Cell Wall

1. **Matrix.** Water— 60%. Hemicellulose— 5–15%. Pectic Substances— 2–8%. Lipids— 0.5–3.0%. Proteins— 1–2%
2. **Microfibrils.** Cellulose/fungus cellulose— 10–15%.
3. **Other Ingredients.** Lignin, cutin, suberin, silica (silicon dioxide), minerals (*e.g.*, iron, calcium, carbonate), waxes, tannins, resins, gum— variable.

Structure of Cell Wall

A cell wall can have upto three parts— middle lamella, primary wall and secondary wall.

Middle Lamella. It is a thin, amorphous and cementing layer between two adjacent cells. Middle lamella is the first layer which is deposited at the time of cytokinesis (Fig. 8.13). It is just like brick work of the common wall between two adjacent rooms. Middle lamella is absent on the outer side of surface cells. It is made up of calcium and magnesium pectates. The softening of ripe fruits is caused by partial solubilisation of pectic compounds to produce jelly-like consistency.

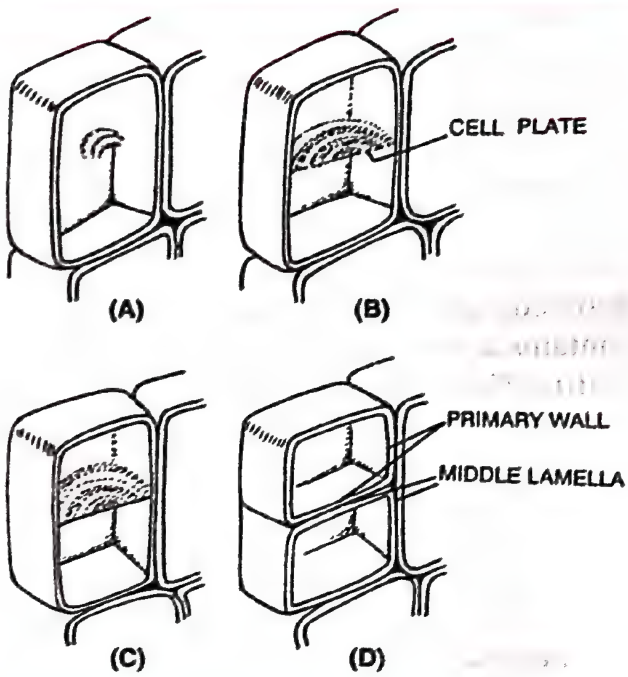


Fig. 8.13. Development of new wall at the time of cytokinesis.

Primary Wall (Fig. 8.14). It is the first formed wall of the cell which is produced inner to the middle lamella. The primary wall is commonly thin (0.1–3.0 μm) and capable of extension. It grows by intussusception or addition of materials within the existing wall. Some cells possess only primary wall, *e.g.*, leaf cells, fruit cells, cells of cortex and pith.

Primary wall consists of a number of **microfibrils** embedded in the amorphous gel-like **matrix** or ground substance. In the majority of plants, the microfibrils are formed of cellulose. They are synthesised at plasma membrane by particle rossettes (terminal complexes) having cellulose synthetase enzyme (Brown *et al*, 1996). The wall is made of a polymer of β, 1–4 acetyl glucosamine or fungus cellulose in many fungi. Fungus cellulose is similar to **chitin** present in the exoskeleton of insects. Microfibrils are oriented variously according to the shape and thickening of the wall. Usually they are arranged in a loose network due to incomplete cross-linking.

The matrix of the wall consists of water, pectin, hemicellulose and glycoproteins. **Pectin** is the filler substance of the matrix. Proteins are **structural** and **enzymatic**. Protein **expansin** (Mc Queen-Mason *et al*, 1992) is involved in loosening and expansion of cell wall through incorporation of more cellulose. **Hemicellulose** binds microfibrils with matrix.

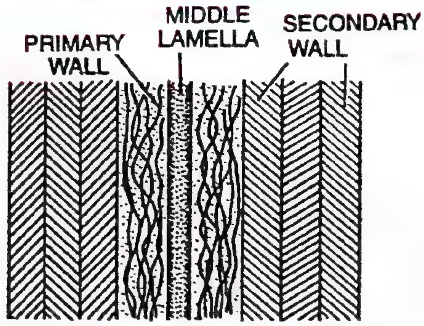


Fig. 8.14. Arrangement of microfibrils in the common wall between two adjacent cells as seen in L.S.

Secondary Wall. It is produced in some mature cells when the latter have stopped growth, *e.g.*, tracheids, vessel elements, fibres, collenchyma. Secondary wall is laid inner to the primary wall by **accretion** or deposition of materials over the surface of existing structure. It is thick (3—10 μm) and made up of at least three layers, sometimes more (*e.g.*, latex tube of *Euphorbia milli*). They are named as S_1, S_2, S_3, S_x, etc. (Fig. 8.15). The innermost layer of the secondary wall is sometimes distinct both chemically as well as in staining properties due to the presence of xylans. It is then called **tertiary wall**, *e.g.*, tension wood in gymnosperms. Secondary wall may be absent, irregularly deposited or formed uniformly in the cells. This results in differentiation of cells— parenchyma, collenchyma, sclerenchyma, tracheids and vessels.

The composition of secondary wall is basically similar to the primary wall in having cellulose microfibrils embedded in a matrix of pectin and hemicellulose. Cellulose microfibrils of the secondary wall lie close, parallel and at an angle to the longitudinal axis of the cell. Their orientation is different in the different layers of the secondary wall (Fig. 8.17). A number of different materials may be deposited in the wall. The important ones are : (a) **Lignin.** It reduces the water content of the wall matrix and increases its hardness. However, water permeability is not affected. The characteristic of lignification (and cutinisation) has evolved with the evolution of land plants. (b) **Suberin.** The wall of cork and endodermal cells contains a special fatty substance called suberin. Suberin makes the walls impermeable. (c) **Cutin.** The epidermal cells possess another fatty substance called **cutin.** Cutin is also laid

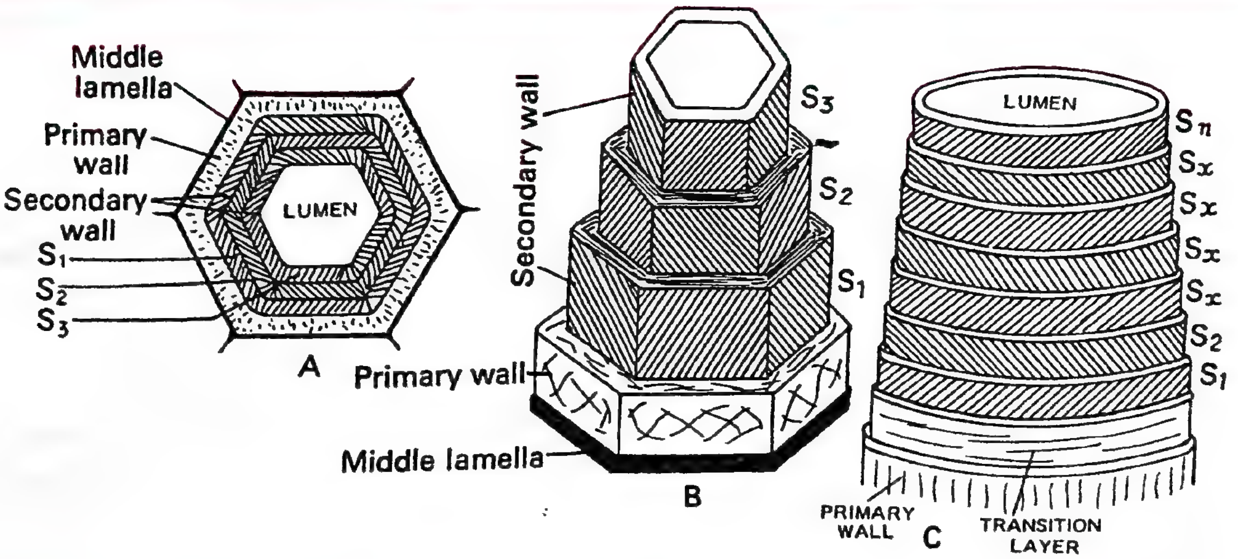


Fig. 8.15. Parts and layers of cell wall. A, a cell in T.S. showing parts of cell wall. B, typical wood fibre cut at various levels to show parts and layers of the wall. C, latex tube of *Euphorbia milli* (= *E. splendens*) cut at various levels to show parts.

as a distinct layer on the outside of the epidermal cell walls. It is known as cuticle. Cutin reduces the rate of epidermal or surface transpiration.

Other substances which can be deposited in the cell wall are silica (*e.g.,* grasses), minerals, waxes, tannins, resins, gums, etc.

Differences Between Primary and Secondary Walls

Primary Wall	*Secondary Wall*
1. Primary wall is laid inner to middle lamella.	1. Secondary wall is laid inner to primary wall.
2. It is formed in young growing cell.	2. Secondary wall is formed when the cell has stopped growing.
3. It is capable of extension.	3. Extensibility is usually absent
4. The wall grows by intussusception or addition of materials inside.	4. It grows by accretion or deposition of materials on the existing structure.
5. It is single layered.	5. Secondary wall is three or more layered.
6. Hydration is 60 %.	6. Hydration is 30—40 %.
7. Cellulose content is comparatively low.	7. Cellulose content is comparatively high.
8. Cellulose microfibrils are shorter, wavy and loosely arranged.	8. Cellulose microfibrils are longer, closely aranged, straight and parallel.
9. Protein content is high, upto 5%.	9. Protein content is low, 1% or less.
10. Hemicellulose content is high, upto 50%.	10. Hemicellulose content is 25% of the total.
11. Lipid content is 5-10%.	11. Lipid is absent or negligible.
12. Additional chemicals like lignin are absent.	12. Lignin, suberin, etc. are present.
13. Primary wall is thin (0.1-3 μm).	13. Secondary wall is quite thick (3-19 μm).
14. Pits are usually absent in a primary wall.	14. Pits often occur in the secondary wall.

Plasmodesmata. Plasmodesmata (Fig. 8.16; singular– plasmodesma; Tangl, 1879; Strasburger, 1901) are cytoplasmic bridges between adjacent plant cells which develop in the minute pores of their walls. They form a protoplasmic continuum called **symplast**. Cell wall and intercellular spaces form a non-living component of the plant body called **apoplasm.** A plasmoderma is 40–50 nm in diameter. It may be simple or branched (Fig. 8.16).

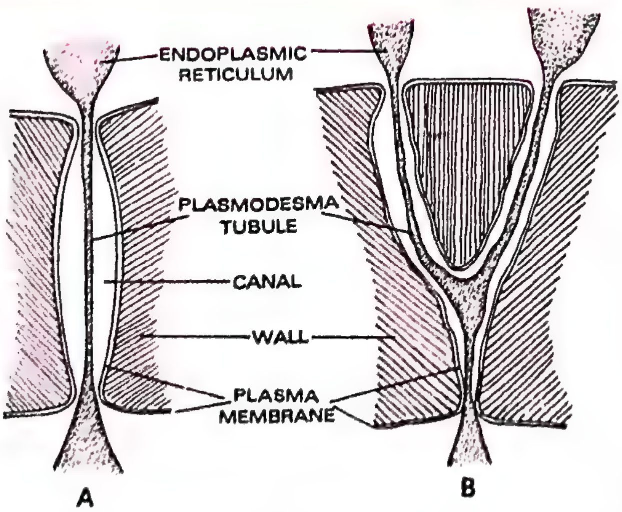


Fig. 8.16. Structure of plasmodesmata. A, simple. B, branched (as between sieve tube cells and companion cells).

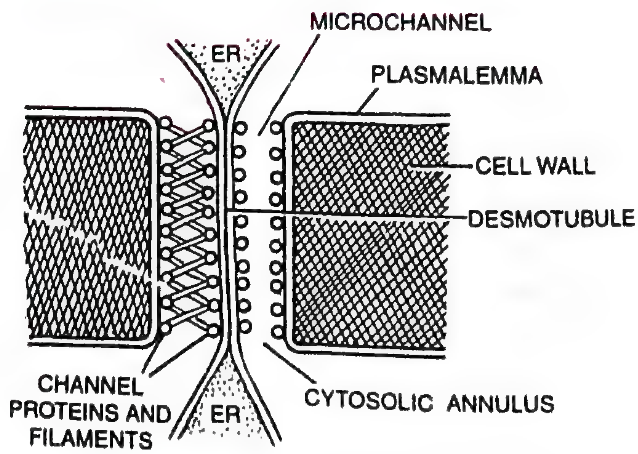


Fig. 8.17. Components of plasmodesmata.

Plasmodesma is lined by plasma membrane. It encloses tubular extension of endoplasmic

reticulum called **desmotubule** (Fig. 8.17). The space between desmotubule and plasma membrane contains 8-10 microchannels (Ding *et al*, 1992). Plasmodesmata form channels for controlled passage of small sized particles between adjacent cells as well as transfer of some specific signals.

Pits. Pits are unthickened areas in the secondary walls of plant cells. They, therefore, appear as depressions. Pits generally occur in pairs on the wall of two adjacent cells. A pit has a cavity or **pit chamber** and a **pit membrane**. The pit membrane consists of primary wall and middle lamella.

Pits are of two types, **simple** and **bordered** (Fig. 8.18). Simple pit has uniform width of the pit chamber. In bordered pit, the pit chamber is flask-shaped because the secondary wall overarches its mouth.

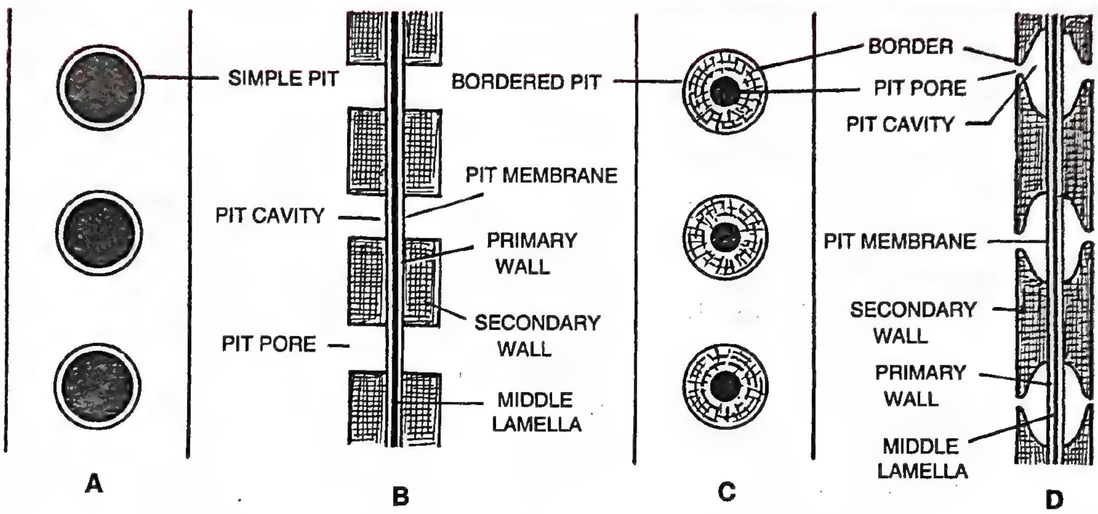


Fig. 8.18. Pits. A, surface view of simple pits. B, simple pit pairs in section. C, surface view of bordered pits. D, bordered pit pairs in section.

Pit membrane is permeable. It may have minute submicroscopic pores. Therefore, pits help in rapid translocation between two adjacent cells.

Cell Coat (Fig. 8.19)

A distinct layer of **glycocalyx** is observed in the outer surface of cells in many animals and protistans. It is fibrous and is made of oligosaccharides. The latter are actually part of the plasma membrane. In some cases cell coat is thickened and strengthened by the deposition of silicon, calcium and other salts. (i) Like cell wall, cell coat is protective in nature. (ii) It provides shape to the cells. (iii) Glycocalyx type of cell coat is useful in recognition between microbe and body cell by white blood corpuscles. (iv) Cell coat helps in cell aggregation and tissue formation. (v) It is involved in histocompatibility. (vi) Blood grouping is based on specific antigens present in the cell coat of erythrocytes.

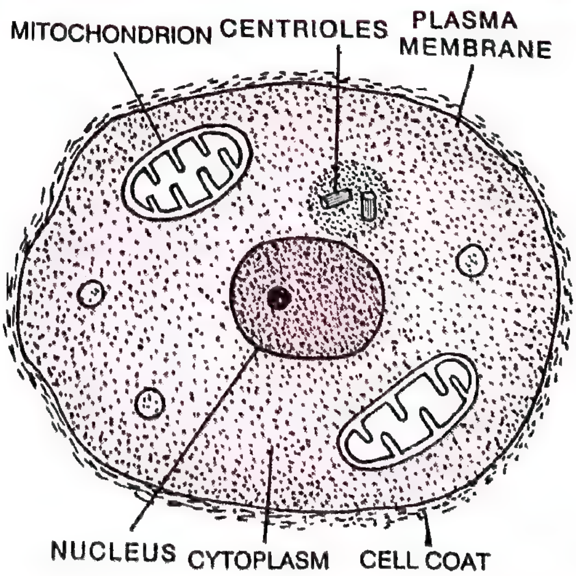


Fig. 8.19. Cell Coat.

II. Cell Membrane

The term was originally used by Nageli and Cramer (1855) for the membranous covering of the protoplast. The same was named plasmalemma by Plowe (1931). Plasmalemma or plasma membrane was discovered by Schwann (1838). Membranes also occur inside the cytoplasm of eucaryotic cells as covering of several cell organelles like nucleus, mitochondria, plastids, lysosomes, Golgi bodies, peroxisomes, etc. They line endoplasmic reticulum, cover thylakoids in plastids or form cristae inside mitochondria. Vacuoles are separated from cytoplasm by a membrane called **tonoplast**.

All membranes, whether external or internal are now called cell membranes or **biomembranes.** They are quasifluid, elastic, pliable and film-like thin partitions over and inside cytoplasm. Average thickness is 75 Å (50–100 Å). Biomembranes are **selectively permeable** for solutes but semipermeable for water. They are dynamic in nature. Any injured part of the membrane is repaired within no time.

Appearance

Biomembranes are not visible under the light microscope because their thickness is below the resolving power of the microscope. Under electron microscope biomembranes appear to be **trilaminar** or **tripartite**. There is an electron dense or dark layer on either side of middle electron transparent layer (Fig. 8.20). Freeze etching technique has shown that a membrane possesses particles of different sizes.

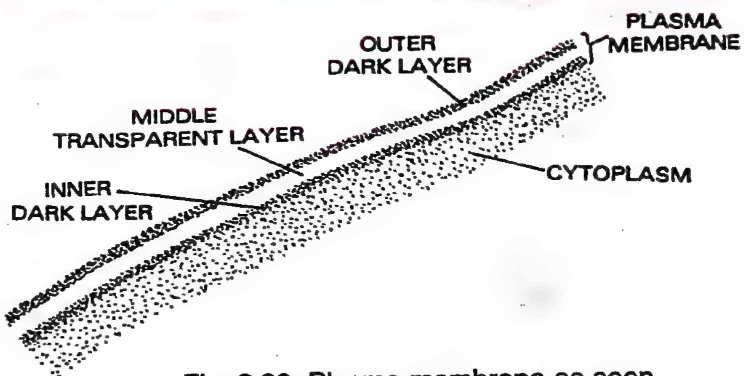


Fig. 8.20. Plasma membrane as seen under electron microscope.

Composition

Chemically a biomembrane consists of **lipids** (20–79%), **proteins** (20–70%), carbohydrates (1-5%) and water (20%). The ratio of protein and lipid varies in different membranes. Human erythrocyte membrane contains 52% protein and 40% lipid while myelinated neuron has 20% protein and 80% lipid. The important lipids of the membrane are **phosphoglycerides** or **phospholipids** (some 100 types). Carbohydrates present in the membrane are branched or unbranched oligosaccharides, *e.g.*, hexose, fucose, hexoamine, sialic acid, etc. Proteins can be fibrous or globular, structural, carrier, receptor or enzymatic.

The lipid molecules are **amphiatic** or **amphipathic**, that is, they possess both **polar hydrophilic** (water loving) and **nonpolar hydrophobic** (water repelling) ends. The hydrophilic region is in the form of a head while the hydrophobic part contains two tails of fatty acids. Hydrophobic tails usually occur towards the centre of the membrane. It results in the formation of a lipid bilayer. Protein molecules also possess both polar and nonpolar side chains. Usually their polar hydrophilic linkages are towards the outer side. The nonpolar or hydrophobic linkages are either kept folded inside or used to establish connections with hydrophobic part of the lipids.

Several types of models have been put forward to explain the structure of a biomembrane. The most accepted is mosaic model.

Lamellar Models (= Sandwich Models, Fig. 8.21)

They are the early molecular models of biomembranes. According to these models, biomembranes are believed to have a stable layered structure.

Danielli and Davson Model (Fig. 8.21A). The first lamellar model was proposed by James Danielli and Hugh Davson in 1935 on the basis of their physiological studies. According to Danielli and Davson, a biomembrane contains four molecular layers, two of phospholipids and two of proteins. Phospholipids form a double layer. The phospholipid bilayer is covered on either side by a layer of hydrated globular or α-protein molecules. The hydrophilic polar heads of the phospholipid molecules are directed towards the proteins. The two are held together by electrostatic forces. The hydrophobic nonpolar tails of the two lipid layers are directed towards the centre where they are held together by hydrophobic bonds and van der Waals forces.

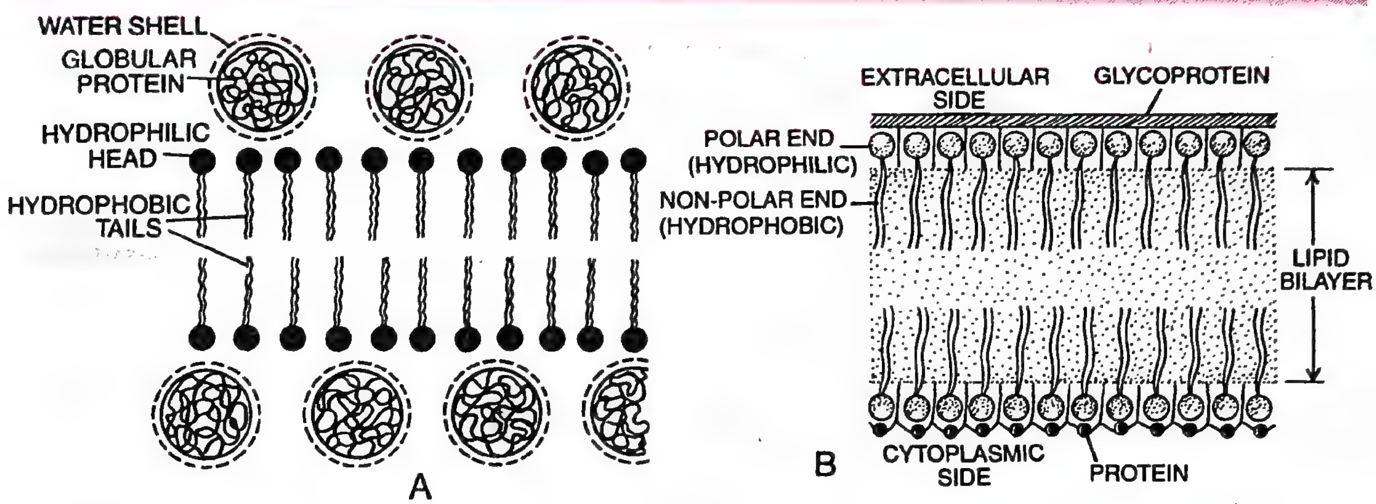


Fig. 8.21. Lamellar models of plasma membrane. A, after Danielli and Davson (1935). B, unit membrane, after Robertson (1959).

Robertson Model (Fig. 8.21B). J. David Robertson (1959) modified the model of Danielli and Davson by proposing that the lipid bilayer is covered on the two surfaces by extended or β-protein molecules. A difference in the proteins of the outer and inner layers was also proposed, *e.g.*, mucoprotein on the outer side and nonmucoid protein on the inner side. Robertson worked on the plasma membrane of red blood cells under electron microscope. He gave the concept of **unit membrane** which means that (i) All cytoplasmic membranes have a similar structure of three layers with an electron transparent phospholipid bilayer being sandwitched between two electron dense layers of proteins. (ii) All biomembranes are either made of a unit membrane or a multiple of unit membrane. The unit membrane of Robertson is also called **trilaminar membrane**. It has a thickness of about 75Å with a central lipid layer of 35Å thick and two peripheral protein layers of 20Å each. According to Robertson, if a membrane contains more than three layers, or is thicker than 75Å, it must be a multiple of unit membrane.

Mosaic Model

Fluid-Mosaic Model (Fig. 8.22). It is the most recent model of a biomembrane proposed by Singer and Nicolson in 1972. According to this model, the membrane does not have a uniform disposition of lipids and proteins but is instead a mosaic of the two. Further, the membrane is not solid but is quasifluid. The quasifluid nature of the biomembranes is shown by their properties of quick repair, dynamic nature, ability to fuse, expand and contract, grow during cell growth and cell division, secretion, endocytosis and formation of intercellular junctions.

Fluid-mosaic model postulates that the lipid molecules are present in a viscous bilayer as in lamellar model. Protein molecules occur at places both inside and on the outer side of lipid bilayer (Fig. 8.22)— **protein icebergs in a sea of lipids**. The internal proteins are called **intrinsic** or **integral** proteins while the external ones are known as **extrinsic** or **peripheral** proteins. The integral or intrinsic proteins account for 70% of the total membrane proteins. They cannot be extracted from the membrane without disrupting the latter (*e.g.*, with detergents). The integral proteins pass into the lipid bilayer to different depths and establish hydrophobic bonds with lipid molecules. Some of the integral proteins run throughout the lipid bilayer. They are called **tunnel proteins** or transmembrane proteins. Transmembrane

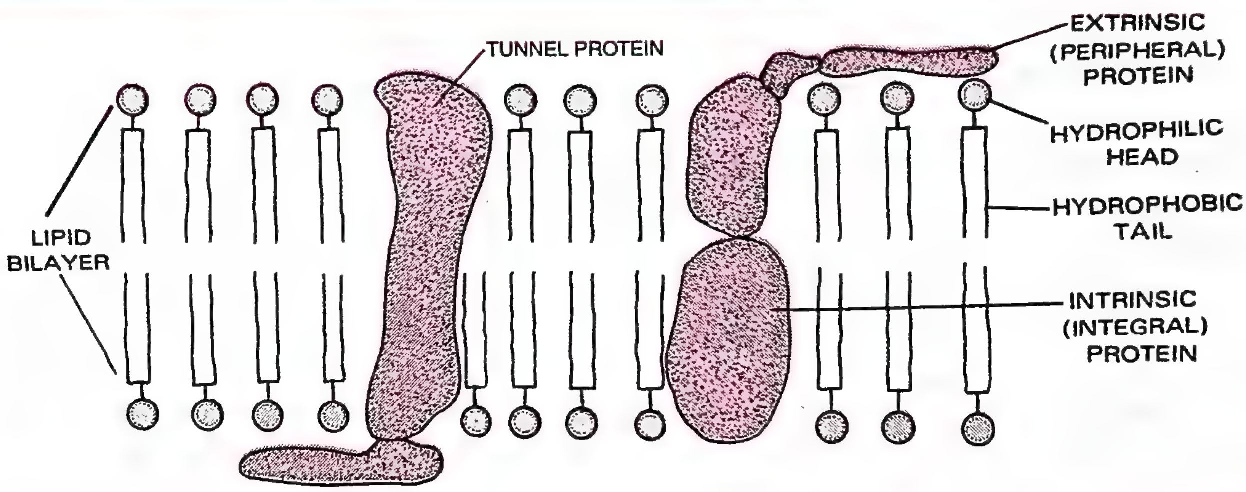


Fig. 8.22. Fluid-mosaic model of biomembrane (after Singer and Nicolson, 1972).

proteins may extend beyond the two surfaces as a single helix (*e.g.*, glycophorins). The tunnel proteins individually or in a group form channels for the passage of water and water soluble substances. The channels, however, possess selective properties for passage of different ions and other polar substances. The proteins are held in their position by both polar (to hydrophilic heads of lipids) and nonpolar (to hydrophobic tails of lipids) side chains. The **extrinsic** or **peripheral** proteins are located superficially on the two surfaces of the membrane, more so on the cytosolic face than on the external face (*e.g.*, **spectrin**). The extrinsic proteins are attached covalently to phospholipid head (anchored proteins) or noncovalently to transmembrane proteins. The latter can be separated with mild treatment. The proteins provide the structural and functional specificity to the membranes. Further, since the lipid bilayer is quasifluid, the membrane proteins may **shift laterally** and thence provide flexibility and dynamism to the membrane. Many membrane proteins function as **enzymes**. Some of

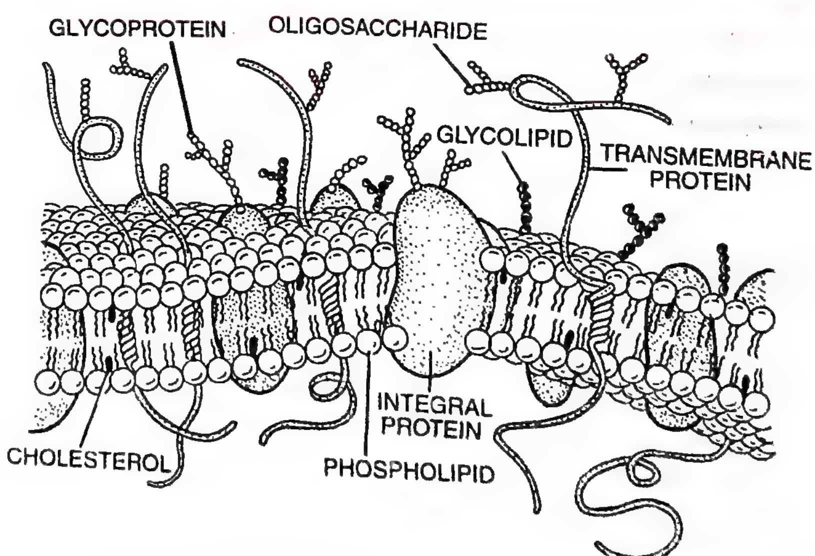


Fig. 8.23. Fluid-mosaic model of a membrane having glycocalyx or carbohydrates attached to outer proteins and lipids.

them behave as **permeases** for allowing facilitated diffusion. A few proteins act as **carriers** because they actively transport different substances across the membrane. Depending upon their role in active transport, carrier can be **uniporters, symporters** and **antiporters.** Certain other proteins function as **receptors** for hormones, recognition centres and antigens. Some lipids and extrinsic proteins present on the outer side possess small carbohyrate molecules to form **glycolipids** and **glycoproteins** (Fig. 8.23). They constitute **glycocalyx** or cell coat. Conjugated oligosaccharides function as recognition centres, sites of attachment, antigens, etc. Oligosaccharides also provide negative charge to the outer surface. Some workers propose the attachment of microfilaments to the membrane for stabilising the protein particles against lateral movement (Heslop-Harrison and Linskens, 1984).

Evidences in support of Fluid Mosaic Model

(1) The model provides for the occurrence of protein particles both on the surface and interior of cell membranes. Freeze etching technique has confirmed the occurrence of particles over and inside the membrane. (2) Fluid mosaic model can explain the presence of different types of permeability and retentivity of various cell membranes. (3) It accounts for dynamic nature of biomembranes with their quick repair. (4) The change in permeability in different parts of the same membrane can be explained. (5) There is experimental evidence for lateral movement of membrane protein indicating the fluidity of the lipid part. (6) The model explains the passage of both electrolytes and non-electrolytes through the biomembranes. (7) It provides for quick growth, expansion and contraction of the membrane. (8) Because of the structural peculiarities of the membrane surfaces, the cells can show various types of interactions including recognition, attachment, antigen, information receptors, etc.

Asymmetry of Biomembranes. The two surfaces of the biomembranes are not similar, *i.e.*, the membranes are asymmetric. (i) Lipids present in the outer and inner side of the bilayer are commonly different, *e.g.*, lecithin on the outer side and cephalin on the inner side of erythrocyte membrane. (ii) The amount and types of extrinsic proteins are different on the two sides. They are more abundant on the inner surface than on the outer surface. (iii) Oligosaccharides are attached to external surface of lipids and proteins of a biomembrane. They are absent on the inner side.

Functions of Cell Membranes

1. The cell membranes cause **compartmentalisation.** As plasma membranes they separate the cells from their external environment. As organelle coverings, they allow the cell organelles to maintain their identity, internal environment and functional individuality.

2. Plasma membrane protects the cell from injury.

3. The membranes allow the flow of materials and information between different organelles of the same cell as well as between one cell and another.

4. As plasmodesmata and gap junctions, the biomembranes provide organic connections between adjacent cells.

5. Plasma membranes of the adjacent cells form various types of junctions for keeping the cells together.

6. Plasma membranes as well as other membranes of the organelles have selective permeability, that is, they allow only selected substances to pass inwardly to selected degrees. The membranes are impermeable to others.

7. Differential permeability and retentivity of plasma membrane as well as other biomembranes control cell metabolism.

8. Plasma membrane possesses specific substances at its surface which function as

recognition centres and points of attachment. Because of this, white blood corpuscles can differentiate between germ and body cells. If cells of different tissues get mixed up and allowed to join on nutrient medium, they move about and regroup to form distinct clusters of specific tissue types.

9. Substances attached to cell membrane determine antigen specificity. Glycophorins present on the surface of erythrocytes function as antigen determinants. Histocompatibility antigens signify whether a foreign cell or tissue should be incorporated or rejected.

10. Cell membrane has receptors for certain hormones. The hormone combines with its particular receptors and either changes membrane permeability or activates enzyme adenylate cyclase to produce cyclic AMP from ATP. cAMP then triggers a set of enzymes to perform a particular function.

11. Membranes have carrier proteins for active transport.

12. Cell membranes contain enzymes for performing certain reaction on their surface, *e.g.*, ATPase (for ATP synthesis and release of energy from ATP), phosphatases, esterases.

13. Certain cell membranes (*e.g.*, plasma membrane in bacteria, thylakoid membranes of chloroplasts, inner mitochondrial membrane) possess electron transport systems.

14. Membrane infolds are used for bulk intake of materials by endocytosis.

15. As microvilli the membrane becomes specialized for absorption of substances.

16. Secretory, excretory and waste products are thrown out by plasma membrane through exocytosis.

17. In nerve cells the cell membrane takes part in transmission of impulses.

18. Plasmalemma provides sheaths for cilia and flagella.

19. Plasma membrane of the cell helps in movement of some cells by either developing undulations (*e.g.*, fibroblasts) or pseudopodia (*e.g.*, *Amoeba*).

Membrane Transport

Passage of substances across biomembranes occur by three methods— passive transport, active transport and bulk transport.

Passive Transport

It is a mode of membrane transport where the cell does not spend any energy nor shows any special activity. The transport is according to concentration gradient. It is of four types — diffusion, osmosis, facilitated diffusion and ion channels (Fig. 8.24–25).

1. **Passive Diffusion or Transport Across Cell Membrane.** Here the cell membrane plays a passive role in the transport of substances across it. Passive diffusion can occur either through lipid matrix of the membrane or with the help of channels.

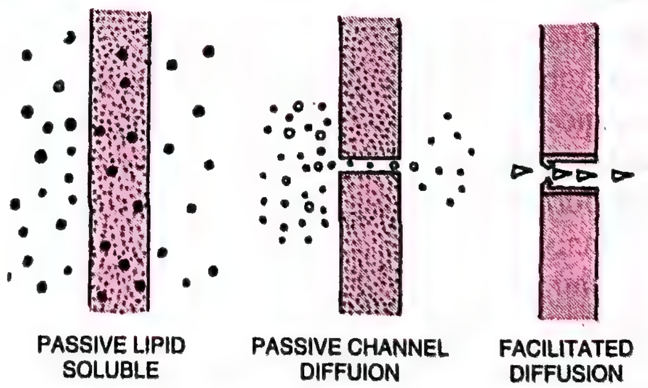


Fig. 8.24. Modes of Passive Transport.

(i) **Neutral Solutes and Lipid Soluble Substances.** Neutral solutes and fat soluble substances can move across the plasma membrane through simple diffusion along their concentration gradient or from the side of higher concentration to the side of their lower concentration. Based on the free movement of lipid soluble substances across the cell membrane, Overton (1900) proposed that cell membranes are made of lipids.

(ii) **Open Channel Transport.** Membranes possess some open channels in the form of tunnel proteins. Water channels or aquaporins allow water and water soluble gases (CO_2 and O_2) to pass through according to their concentration gradient. **Osmosis** is an example of such a transport. **Filtration** is diffusion under pressure across a membrane having minute pores. **Ultrafiltration** or fine filtration occurs during glomerular filtration inside kidneys. **Dialysis** is the process of separating small particles (*e.g.*, crystalline solutes) from larger ones (*e.g.*, colloids) due to difference in the rate of diffusion across a membrane having very minute pores. It is carried out during separation of waste products from blood in artificial kidney.

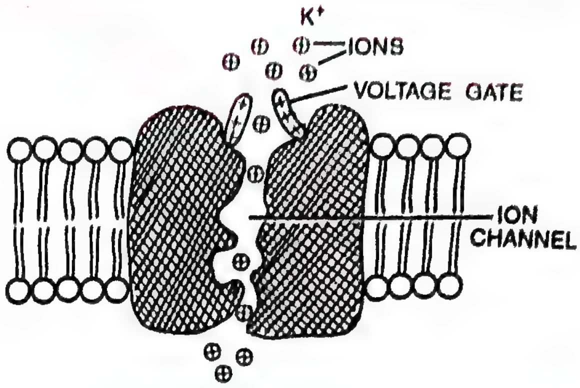


Fig. 8.25. A voltage gated K^+ channel.

(iii) **Ion channels** are highly specific. There is a specific channel for each ion. Ions do not pass in dissolved state through ion channels but instead only ions move through them. Most ion channels are **gated** (Fig. 8.25). Depending upon the stimulus required for opening the gates of the ion channels, they are of four types — voltage gated, mechanical gated, temperature gated and ligand gated. More than 100 ion channels have been discovered. Movement through ion channels is according to concentration gradient. The rate of passage is quite high.

Aquaporins are channels specialized to transport water.

(iv) **Permeases.** Permeases function as facilitated pathways for the movement of substances. As a result the rate of transport is stereospecific. Saturation effect is recorded.

Active Transport

It is uphill movement of materials across the membrane where the solute particles move against their chemical concentration or electro-chemical gradient. Energy is required for the process (Fig. 8.26). It is obtained from ATP. Active transport occurs in case of both ions and nonelectrolytes, *e.g.*, salt uptake by plant cells, glucose and phenolphthalein in case of renal tubules, sodium and potassium in case of nerve cells, etc. It is supported by various evidences (i) Absorption is reduced or stopped with the decrease in oxygen content of the surrounding environment. (ii) Metabolic inhibitors like cyanides inhibit absorption. (iii) Active transport is also inhibited by substances similar to solutes. (iv) Absorption of different substances is selective. (v) Cells often accumulate salts and other substances against their concentration gradient. (vi) Decrease in temperature decreases absorption. (vii) Active transport is more rapid than diffusion. (viii) It shows **saturation kinetics**, that is, the rate of transport increases with increase in solute concentration till a maximum is achieved. Beyond this value the rate of membrane transport does not increase indicating that it takes place through the agency of special organic molecules called **carrier molecules, carrier particles** or **carrier proteins**. There is a special carrier molecule for each solute particle (ion or molecule). The carrier has its binding site on two surfaces of the membrane. The solute particle (or substrate) combines with the carrier to form **carrier solute complex**. In the bound state the carrier undergoes a conformational change (Fig. 8.26) which transports the solute to the other side of the membrane. Here the solute is released. Energy is used in bringing about the conformational change in the carrier. It is provided by ATP. In the process ATP is dephosphorylated to form ADP.

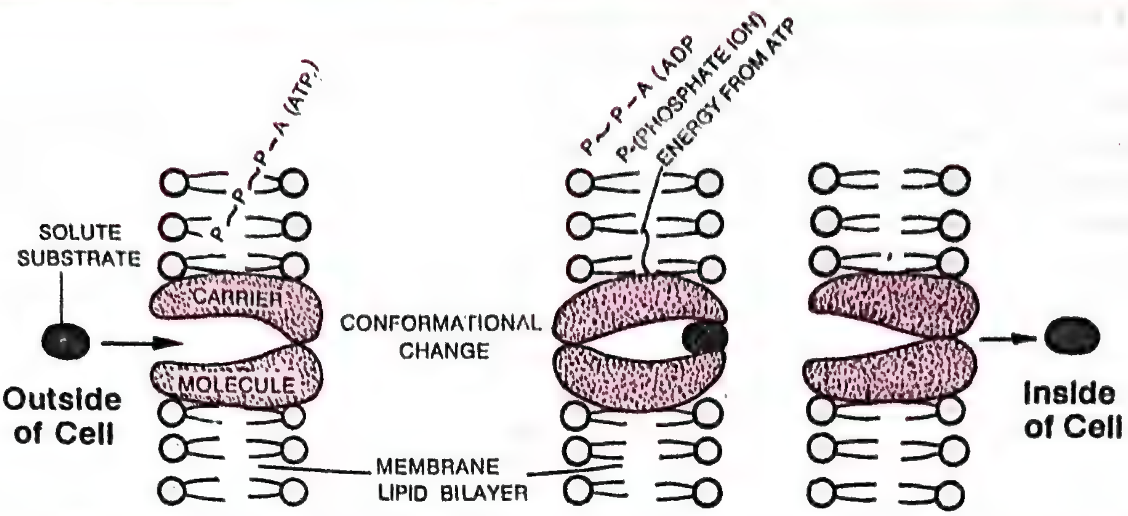


Fig. 8.26. Active transport across the membrane through a carrier molecule.

Many animal cells operate a **sodium-potassium exchange pump** (Fig. 8.27) at their plasma membrane. A similar proton pump operates in chloroplasts, mitochondria and bacteria. Na^+ — K^+ exchange pump operates with the help of enzyme ATP-ase which also functions as a carrier molecule. The enzyme hydrolyses ATP to release energy. The energy is used in bringing about conformational changes in the carrier. For every ATP molecule hydrolysed, three Na^+ ions are pumped outwardly and two K^+ ions are pumped inwardly. Na^+ — K^+ exchange pump performs the following functions : (i) Maintains a positive potential on the outer side of the membrane and relatively electro-negative potential on the inner side. (ii) The pump creates a resting potential in the nerve cells. (iii) The pump maintains water balance of living cells. (iv) It helps in urine formation. (v) It takes part in excretion of salt as in marine animals. Sea gulls and penguins drink sea water. They excrete excess salt through nasal glands. The nasal salt glands have sodium-potassium pump in the plasma membranes of their cells. Na^+ ions are jumped out actively. Chlorine ions pass out passively. Nasal secretion of the two birds possess 1.5–3.0 times more NaCl concentration than the one present in the blood. (vi) The unsecreted and unmetabolised excess Na^+ ions present in the extra-cellular fluid have a tendency to pass back into the cells. Other substances combine with sodium ions and pass inwardly alongwith them, *e.g.*, glucose, amino acids in intestine. The phenomenon is called **secondary active transport** as compared to Na^+— K^+ exchange pump which is called **primary active transport**. Secondary active transport uses free energy made available by the primary active transport. A lot of heat is produced by utilisation of ATP in primary active transport during its conversion into kinetic energy.

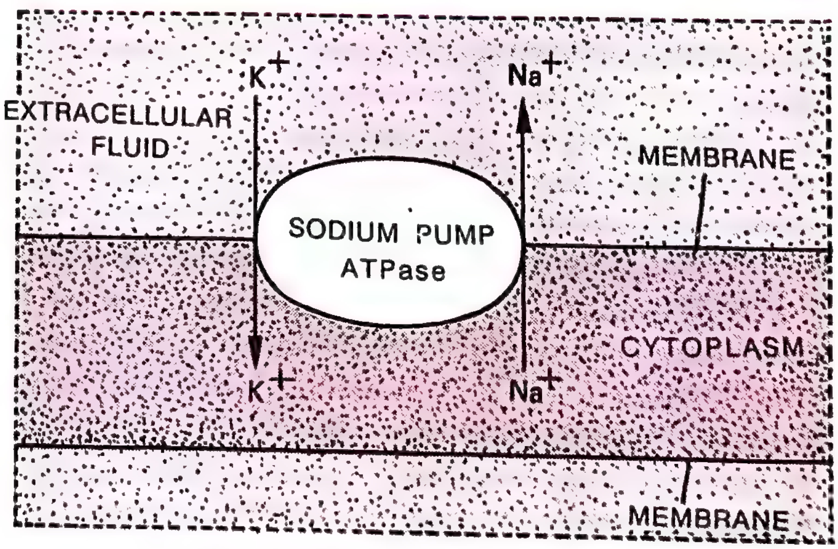


Fig. 8.27. Sodium Potassium Pump.

Other important pumps include **Calcium pump** (RBCs, muscles), **K^+ pump, Cl^- pump, K^+—H^+ exchange pump**. The last one occurs in guard cells. **Proton pumps** are specialised to help in ATP synthesis in mitochondria and chloroplasts.

Active transport is a means of (i) absorption of most nutrients from the intestine (ii) reabsorption of useful material from the uriniferous tubules (iii) rapid and selective absorption of nutrients by cells (iv) maintaining a membrane potential (v) maintenance of resting potential in nerve cells (vi) maintaining water and ionic balance between cells and extra cellular fluid (vii) excretion by salt glands (viii) absorption of substances against concentration gradient.

Differences between Active Transport and Passive Transport (Diffusion)

Active Transport	*Passive Transport*
1. The transport involves an expenditure of energy by the cells.	1. The cells do not spend energy in passive transport.
2. Active transport usually occurs against concentration or electrochemical gradient.	2. Passive transport is always along the concentration or electrochemical gradient.
3. It helps in the accumulation of substances in the cells.	3. Passive transport does not allow accumuation of substances in the cell.
4. Active transport is a vital process.	4. It is a physical process.
5. It requires carrier proteins. Matrix or permeases of the membrane are not involved.	5. Carrier proteins are not involved. It takes place through matrix/channels/permeases.
6. It is highly selective.	6. Passive transport is partly nonselective. All diffusible substances can be transported according to their concentration gradient.
7. Active transport is a rapid process.	7. It is a comparatively slow process.
8. Active transport occurs in one direction.	8. Passive transport is bidirectional.
9. It is reduced or stopped with O_2 deficiency.	9. Passive transport is unaffected by O_2 content.
10. Metabolic inhibitors stop active transport.	10. Metabolic inhibitors do not influence passive transport.
11. Decrease in temperature decreases it.	11. It is not affected by temperature.

Bulk Transport

It occurs by two methods, pinocytosis and phagocytosis. They involve the enclosure of the material under transport in the vesicles of the membrane. The latter are, therefore, also called carrier vesicles. The vesicles are formed in response to chemical stimuli. The inward transport by means of carrier vesicles is called **endocytosis** (Gk. *endon*– within, *kytos*– cell). The outward transport of substances by means of carrier vesicles is known as **exocytosis** (Gk. *exo*– outside, *kytos*– cell). It is quite common in secretory and excretory cells.

Pinocytosis or Potocytosis (Gk. *pinein* or *potos*– to drink, *kytos*– cell, Fig. 8.28). It is the bulk transport of fluid matter and substances dissolved in it (*e.g.*, ions, sugars, amino acids) across the cell membrane by forming minute detachable vesicles of 100–200 nm diameter. Pinocytosis is also called **cell drinking**. Solute intake may be selective or nonselective. Selective solute intake occurs through specific pits having receptor sites. As soon as solute or **ligand** particles form complexes with receptor sites, plasma membrane invaginates. The invagination deepens and gets pinched off as a vesicle called **pinosome** (Lewis, 1931). The pinosome migrates towards the interior where it liberates the materials

either in the cytoplasm or a vacuole. Lysosomes are required if digestion of solutes is involved. Pinocytosis is quite common in the cell lining the blood capillaries. Macromolecules enter cells only through pinocytosis.

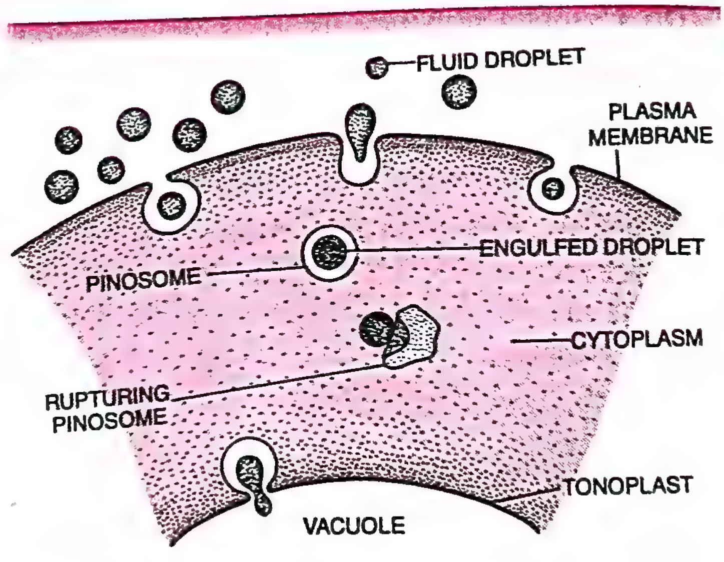


Fig. 8.28. Bulk transport of fluid substances by pinocytosis.

Phagocytosis (Gk. *phagein*– to eat, *kytos*– the cell, Fig. 8.29). It is also called **cell eating**. Phagocytosis is the transport of solid matter like food, foreign particles, pathogens, etc. across the membrane by forming detachable vesicles. These vesicles are called **phagosomes**. They are formed by invagination of plasma membrane in the region of solid particles, rapid evagination on the periphery, formation of a vesicle and pinching off the latter into the interior as **phagosome**. A phagosome is 1–2 µm in diameter. It fuses with a lysosome to produce a **digestive vacuole**. The solid food is digested. The digested food diffuses into the cytoplasm. The vacuole containing the indigestible substances is called **residual vacuole**. The undigested parts are usually thrown out of the cell in the process of exocytosis called **ephagy** or **cell vomiting**. Phagocytosis by some white blood corpuscles is an important defence mechanism of the animal body. Some 100 billion old erythrocytes are destroyed every day in the human body through phagocytosis in spleen and liver.

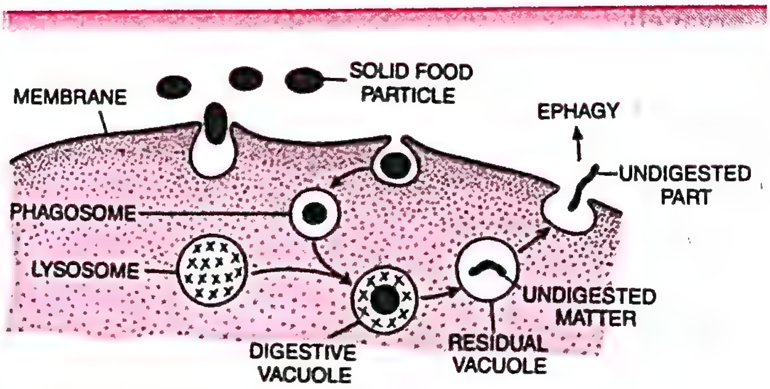


Fig. 8.29. Phagocytosis.

Differences between Pinocytosis and Phagocytosis

Pinocytosis	*Phagocytosis*
1. It is the bulk intake of fluid materials by a cell.	1. Phagocytosis is the intake of solid material from outside to the inside of the cell.
2. Vesicles formed in pinocytosis are small.	2. Vesicles formed in phagocytosis are large.
3. Membrane possesses receptor pits for receiving the materials.	3. Receptor pits are absent.
4. Membrane does not show evagination during pinocytosis.	4. Membrane evaginates on the periphery to engulf the solid particle.
5. Digestion or breakdown of absorbed substances may or may not occur. Accordingly a food vacoule may or may not be formed.	5. A digestive or food vacuole is formed from a phagosome.
6. Lysosomes play no role in utilization of absorbed materials if digestion is not involved.	6. Lysosomes are essential because solid substances taken in by phagocytosis require digestion.
7. There is no exocytosis or ephagy.	7. The undigested parts of the solid particle are thrown out by exocytosis or ephagy.

III. Cytoplasm (Strasburger, 1882)

Cytoplasm is jelly-like semi-fluid general mass of protoplasm excluding the nucleus but including all other components— cytoplasmic matrix, cell organelles and cell inclusions.

(A) Cytoplasmic Matrix or Cytosol (Hyaloplasm)

It is the clear fluid part of the cytoplasm which can exist in two states, **sol** and **gel**. The two are respectively called **plasmasol** and **plasmagel**. Plasmagel is usually present below the plasma membrane. It is called **ectoplast**. Plasmasol is internal and is known as **endoplast**. Water constitutes 90% of the matrix. Matrix is actually a crystallo-colloidal complex in water where some chemicals are present in the form of a true solution while others are present as colloidal solution, *e.g.*, minerals, sugars, amino acids, tRNAs, nucleotides, vitamins, proteins, enzymes, etc. Proteins are the major colloidal particles of the complex. Fats usually occur as emulsion either in the form of globules in the matrix or as component of various biomembranes.

Cytoplasmic matrix performs a number of functions. Important ones are :

(i) *Raw Materials*. The matrix contains raw materials and provide the same to cell organelles for their functioning.

(ii) *Exchange*. The cell organelles are usually unconnected. They exchange materials through the cytoplasmic matrix.

(iii) *Products*. The products of cell organelles are passed out into the matrix.

(iv) *Biosynthesis*. The matrix is the seat of synthesis of a number of biochemicals like fats, nucleotides, some carbohydrates, proteins, coenzymes, etc.

(v) *Catabolic Activities*. Glycolysis, anaerobic respiration and pentose pathway type of respiration occur in the matrix part of cytoplasm.

(vi) *Cytoplasmic streaming*. The cytoplasmic matrix is always in motion. It is autonomic and is called cytoplasmic or protoplasmic streaming (Amici, 1818). This helps in distribution of various materials inside the cell.

(B) Cell Organelles

They are sub-cellular structures with characteristic morphological forms, distinctive chemical constitutions and definite functions, which can be carried out by them even outside the cytoplasm provided they are supplied with substances which are normally provided by the cell. A cell contains a number of organelles like mitochondria, plastids (of several types), endoplasmic reticulum, Golgi complex, lysosomes, microbodies, ribosomes, etc.

ENDOMEMBRANE SYSTEM

It is a grouping of protein trafficking membrane organelles which function in close coordination with one another, *viz*., endoplasmic reticulum, Golgi complex, lysosomes and vacuoles. Functions of other organelles are not coordinated. They are not part of endomembrane system, *e.g.*, plastids, mitochondria, peroxisomes, glyoxisomes, etc.

1. Endoplasmic Reticulum (ER)

It was discovered independently by Porter (1945) and Thompson (1945). The name was given by Porter in 1953. *Endoplasmic reticulum is a 3-dimensional, complicated and interconnected system of membrane-lined channels that run through the cytoplasm* (Fig. 8.39). At places, it is connected with plasmalemma as well as nuclear envelope. Plasmodesmata

contain it in the form of desmotubules. It is not visible under light microscope but can be observed under electron microscope.

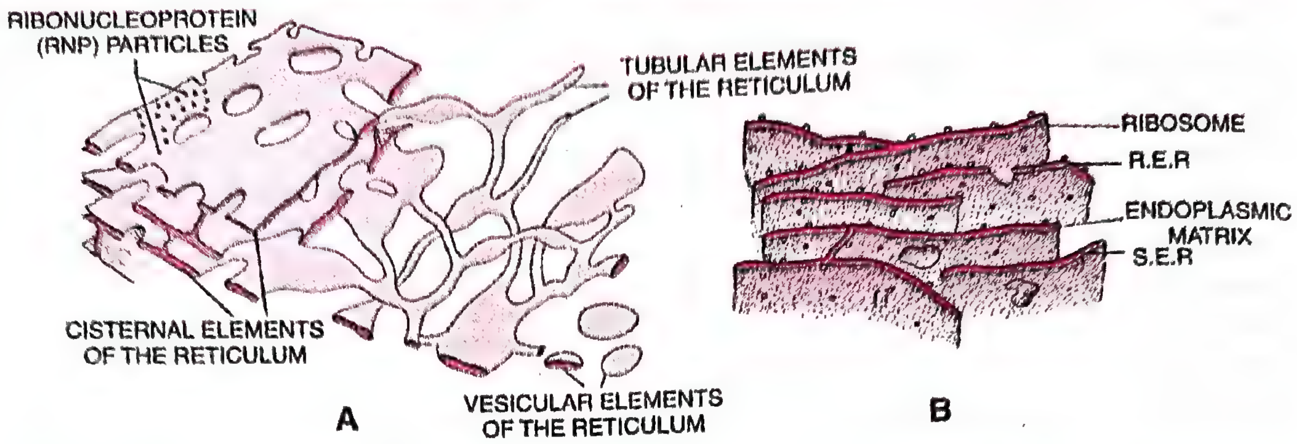


Fig. 8.30. Part of endoplasmic reticulum showing its three dimensional nature.

Endoplasmic reticulum divides the intracellular space into two compartments **luminal** (inside the endoplasmic reticulum) and **extra-luminal** (rest of cytoplasm).. The extent of endoplasmic reticulum varies from cell to cell. Normally it forms 30–60% of membrane system of the cell which increases the internal surface 30–40 times as compared to external surface. Endoplasmic reticulum is quite extensive in metabolically active cells (*e.g.*, cells of pancreas, liver), simple in storage cells (in the form of tubules in adipose cells), reduced in spermatocytes (in the form of a few vesicles), and absent in eggs, mature erythrocytes, embryonic cells, resting cells, prokaryotic cells, etc.

Types. Depending upon the nature of its membranes, endoplasmic reticulum is of two main types, **smooth** and **rough.** The two types of ER may be continuous with one another, plasma membrane and nuclear envelope. Endoplasmic reticulum may develop from pre-existing E.R., plasmalemma or nuclear envelope.

Smooth Endoplasmic Reticulum (SER). It has smooth membranes which do not bear ribosomes. It is, therefore, also called **agranular endoplasmic reticulum**. This type of ER is found in cells engaged in the synthesis and storage of glycogen, fat and sterols (*e.g.*, glycogen storing liver cells, interstitial cells, adrenal cortical cells, adipose cells, muscle cells, retinal cells, etc). It is also comsmonly found in leucocytes. Smooth endoplasmic reticulum is mostly made of vesicles and tubules. Sphaerosomes are believed to originate from SER.

Rough Endoplasmic Reticulum (RER). It has rough membranes because a number of ribosomes occur attached to their outer surfaces. RER is, therefore, also called **granular endoplasmic reticulum.** The membrane of the endoplasmic reticulum bears a fine pore in the area of attached ribosome to pass the synthesised polypeptide into the channel of endoplasmic reticulum for transport. RER contains two types of glycoproteins (ribophorin I and ribophorin II) for attachment to ribosomes. On account of the presence of ribosomes, the rough ER is engaged in synthesising proteins and enzymes. It is, rich in cells which are actively engaged in protein synthesis and secretory acitivity, *e.g.*, pancreatic acinus cells, plasma cells, fibroblasts, goblet cells. In conjunction with Golgi apparatus, RER helps to produce lysosomes. RER is mostly made of cisternae. Tubules are very few.

Differences between SER and RER	
SER	*RER*
1. SER does not bear ribosomes over the surface of its membranes.	1. RER possesses ribosomes attached to its membranes.
2. It is mainly formed of vesicles and tubules.	2. It is mainly formed of cisternae and a few tubules.
3. It is engaged in the synthesis of glycogen, lipids and steroids.	3. The reticulum takes part in the synthesis of proteins and enzymes.
4. SER gives rise to sphaerosomes.	4. It helps in the formation of lysosomes through the agency of Golgi apparatus.
5. Pores are absent so that materials synthesised by SER do not pass into its channels.	5. RER possesses narrow pores below its ribosomes for the passage of synthesised polypeptides into ER channels.
6. SER is often peripheral. It may be connected with plasmalemma.	6. It is often internal and connected with nuclear envelope.
7. Ribophorins are absent.	7. RER contains ribophorins for providing attachment to ribosomes.
8. It may develop from RER.	8. It may develop from nuclear envelope.
9. It has enzymes for detoxification.	9. The same are absent.
10. Vesicles for *cis*- face of Golgi apparatus are provided by SER.	10. It provides biochemicals for Golgi apparatus.

Structure. Endoplasmic reticulum consists of membrane lined channels or spaces. The channels or spaces contain a fluid called **endoplasmic matrix**, which is quite different from cytoplasmic matrix present outside the reticulum. The membranes of endoplasmic reticulum are 50–60 Å thick. Endoplasmic reticulum can exist in three forms (Fig. 8.31)— cisternae, vesicles and tubules.

1. **Cisternae.** They are flat interconnected sac-like parts of the endoplasmic reticulum which are 40–50 nm in diameter. The cisternae are found in bundles where they lie parallel to one another. They occur in the cells actively involved in synthetic activity.

2. **Vesicles.** They are oval or rounded sacs of 25–500 nm in diameter. The vesicles appear as small vacuoles. They remain isolated in the cytoplasm. The vesicles are also called **microsomes.**

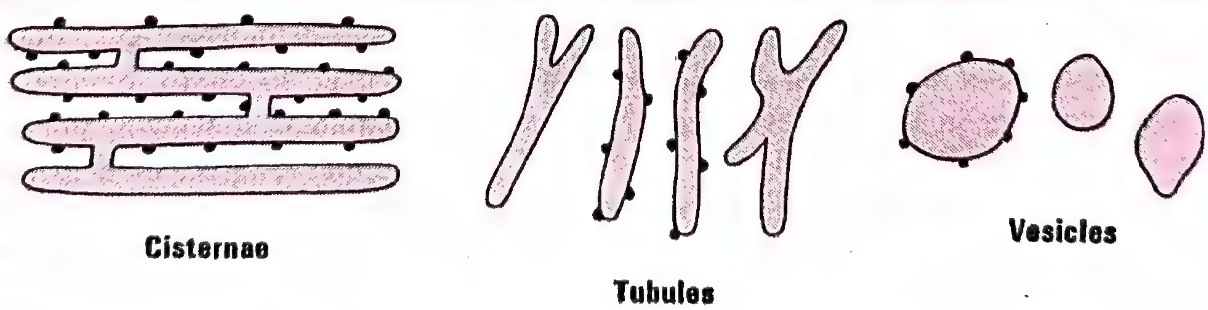


Fig. 8.31. The three components of endoplasmic reticulum.

3. **Tubules.** They are tube-like extensions which may be connected with cisternae or vesicles to form a reticular system. The tubules can be irregular or regular, branched or unbranched with a diameter of 50–100 nm.

FUNCTIONS

Common Functions of ER

1. It provides a large surface inside the cell for various physiological activities.
2. It functions as cytoskeleton or intracellular and ultrastructural skeletal framework by providing mechanical support to colloidal cytoplasmic matrix.
3. Endoplasmic reticulum keeps the various organelles in their position.
4. Endoplasmic reticulum (as **desmotubules**) controls movement of materials between two adjacent protoplasts through plasmodesmata.
5. Endoplasmic reticulum acts as a means of quick intracellular transport.
6. In cells, endoplasmic reticulum conducts information from cell exterior to inside and from one part of the cell to another, *e.g.*, cytoplasm to nucleus and *vice versa.*
7. It provides membranes to nuclear envelope after telophase.
8. It provides precursors of different secretory substances to Golgi apparatus.
9. It gives membranes to Golgi apparatus for the formation of vesicles and lysosomes.
10. It gives rise to vacuoles.
11. Complexing of proteins and lipids to form lipoproteins occur in ER.
12. The membranes of endoplasmic reticulum contain a number of enzymes (*e.g.*, ATP-ase, reductases, dehydrogenases, phosphatases) for various metabolic activities and cytochromes that take part in electron transport.

Functions of Rough Endoplasmic Reticulum (RER)

1. It contains SRP receptors or ribophorins for providing attachment to ribosomes.
2. RER provides a large surface area to ribosomes.
3. It bears enzymes in the region of pores for modifying polypeptides synthesised by attached ribosomes, *e.g.*, glycosylation.
4. It synthesises serum proteins, membrane proteins and a number of other proteins.
5. Proteins and enzymes synthesised by ribosomes enter the channels of RER both for intracellular use as well as secretion.
6. It provides enzyme precursors for the formation of lysosomes by Golgi complex.
7. SER can develop from RER by discarding ribosomes.

Functions of Smooth Endoplasmic Reticulum. (1) It is responsible for synthesis of fats inside the cells of adipose tissue, formation of sphaerosomes, synthesis of glycogen as well as glycogenolysis (hydrolysis of glycogen) in liver cells (for this, SER possesses enzyme bodies called **glycosomes**) synthesis of ascorbic acid, synthesis of sterols and steroid hormones as in the interstitial cells of testis and ovary and formation of visual pigments from vitamin A in retinal cells.

(2) As sarcoplasmic reticulum, it stores Ca^{2+} for release during muscle contraction.

(3) It takes part in detoxification of toxic chemicals with the help of cytochrome P-450.

(4) Synthetic products of RER pass on to Golgi complex through SER.

(5) P-450 and P-448 help in metabolising harmful chemicals.

2. Golgi Apparatus or Golgi Complex

Golgi complex (Golgi Apparatus, Dalton Complex, Apparato Reticulare) is a complex cytoplasmic structure made up of smooth membrane saccules or cisternae, a network of tubules with vesicles and vacuoles, which takes part in membrane transformation, secretion

and production of complex biochemicals. It is surrounded by an organelle free cytoplasm called **zone of exclusion** or **Golgi ground substance.** It was first seen by George (1867) but is named after Italian scientist Camillo Golgi, who in 1898 recognised the apparatus as reticular structure (apparato reticulare) near the nucleus. In the nerve cells of barn owl and cat by means of **metallic impregnation** method. Its structure was studied under electron microscope by Dalton and Felix (1954).

Occurrence. Golgi apparatus or complex is absent in prokaryotic cells (PPLO, bacteria and blue-green algae). It is present in all eukaryotic cells except sieve tubes of plants, sperms of bryophytes and pteridophytes and red blood corpuscles of mammals.

Location. In animal cells Golgi complex or apparatus is either single or consists of a single connected complex. The two conditions are respectively called **localised** (most vertebrate cells) and **diffused** (most invertebrate cells, liver and nerve cells of vertebrates). The localised organelle is compact. It generally occurs at one end between the nucleus and the periphery. The diffused organelle is found to form a network, *e.g.*, around the nucleus in nerve cells.

In plant cells, Golgi apparatus is formed of a number of *unconnected units* called **dictyosomes**. Their number is highly variable— from one in certain simple algae to 25000 in rhizoidal cell of *Chara*. Commonly there are 10–20 dictyosomes per plant cell. A liver cell may possess upto 50 units of Golgi apparatus called Golgisomes.

Structure. The shape and size of Golgi complex are not fixed. They depend upon the physiological state of the cells. A typical plant dictyosome is 0.5–1.0 μm in diameter. Usually Golgi complex is made up of four parts— **cisternae, tubules, vesicles** and **vacuoles** (Fig. 8.32).

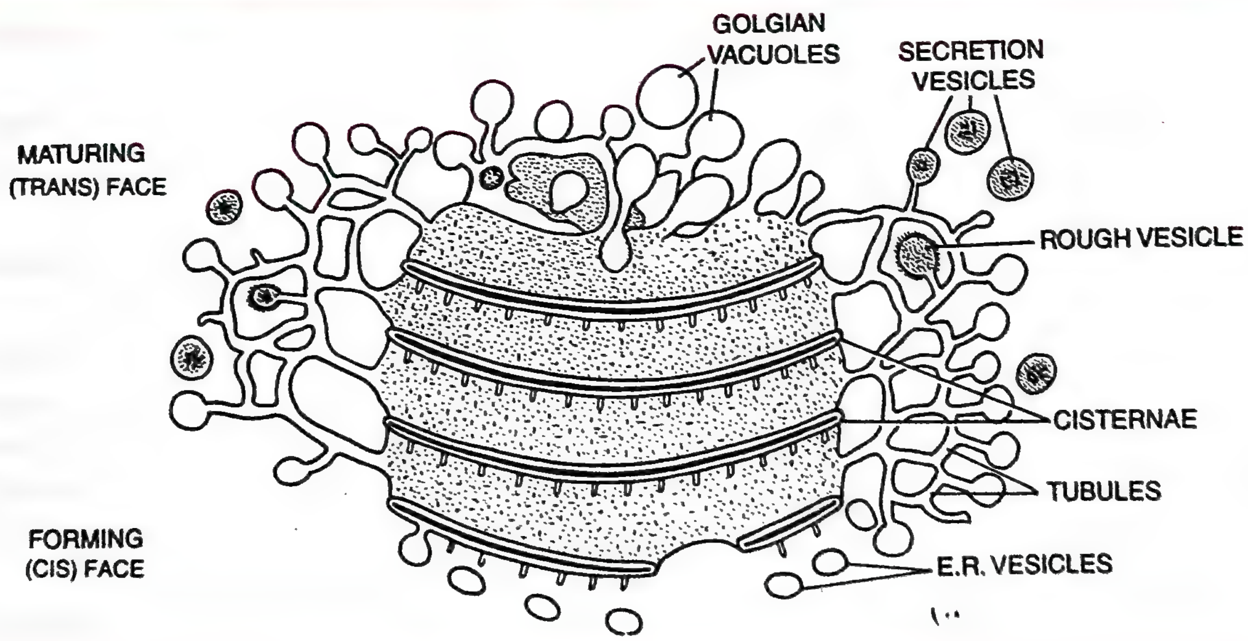


Fig. 8.32. Structure of Golgi apparatus (dictyosome)

Cisternae. Golgi complex consists of a stack of generally 4–8 (range 3–20) membrane bound **saccules** or **cisternae**. Unicisternal dictyosomes are found in fungi.

The membranes of the saccules or cisternae are smooth but of variable thickness. They enclose a lumen of 60–90 Å. Lumen contains a fluid substance or matrix. In a stack, the

adjacent cisternae are separated by a distance of 100–300 Å. The intercisternal space contains thin layer of cytoplasm having parallel fibrils.

The saccules are frequently curved to give a definite polarity to the Golgi apparatus. One face of the apparatus is convex while the other is concave. The **convex** side is called **forming** (=formative, *cis*-face) face while the **concave** side of the apparatus is known as **maturing face** (*trans*-face). The cisterna of the *cis*-face is larger and fenestrated. It produces a *cis*-Golgi network or CGN. The cisterna at the *trans*-face is smaller but also fenestrated. It forms a *trans*-Golgi network or TGN. The cisternae or saccules of middle are known as medial Golgi stacks. The membranes of the maturing face are 7–8 nm in thickness while those of the forming face are about 4 nm in thickness. The forming face receives (transitional) vesicles from endoplasmic reticulum with the help of motor proteins. Their contents pass through various cisternae with the help of coated vesicles and intercisternal connectives. They ultimately reach the maturing face where they are budded off as secretion, coated or Golgian vesicles or vacuoles. While passing through the apparatus, biochemicals are variously transformed.

Tubules. They form a complicated network towards the periphery and maturing face of the apparatus. Actually tubules arise due to fenestrations of the cisternae. They have a diameter of 30–50 nm. The tubules interconnect the different cisternae.

Vesicles. They are small sacs of 20–80 nm diameter. The vesicles are found attached to the tips of tubules at various levels in the network. They are of two types, **smooth** and **coated.** The coated vesicles have a rough surface. They elaborate membrane proteins. The smooth vesicles have a smooth surface. They contain secretory substances and are hence known as **secretion vesicles.**

Golgian Vacuoles. They are expanded parts of the cisternae which have become modified to form vacuoles. The vacuoles develop from the concave or maturing face. Golgian vacuoles contain amorphous or granular substance. Some of the golgian vacuoles function as lysosomes.

Functions

1. **Secretion.** All glandular cells depend upon Golgi complex for concentrating and packaging their products inside a soluble protein coat visible as dark staining under electron microscope. They are sent out of the cells through **exocytosis** or **reverse pinocytosis.**
2. **Transformation of Membranes.** Golgi complex brings about membrane transformation, that is, converting one type of membrane (*e.g.*, that of ER) into other types (*e.g.*, selectively permeable plasma membrane, differentiated membrane of lysosome). The complex also takes part in the recycling of plasma membrane.
3. **Glycoproteins and Glycolipids.** Proteins synthesised by the rough endoplasmic reticulum and lipids synthesised by smooth endoplasmic reticulum reach the cisternae of the Golgi apparatus. Here, they combine with carbohydrates to form glycoproteins and glycolipids.
4. **Special Simple Carbohydrates.** Sialic acid and galactose are made inside Golgi complex.
5. **Complex Carbohydrates.** Most of the complex carbohydrates, other than glycogen and starch, are synthesised inside the Golgi complex, *e.g.*, pectic compounds, mucopolysaccharides, hyaluronic acid, chondroitin sulphate, hemicellulose, etc.
6. **Hormones.** Production of hormones by endocrine glands is mediated through it.
7. **Matrix.** Matrix of connective tissue is formed by Golgi complex of its cells.
8. **Fat Transport.** Fatty acids and glycerol absorbed by intestinal epithelium are transferred as fat to lacteal through Golgi complex.
9. **Synthesis of Pigments.** In Chick embryo the retinal pigment has been observed to be synthesised by Golgi complex (Beams and Kessels, 1968).

10. **Formation of Acrosome.** Acrosome is an important constituent of the tip of animal sperms which helps in digesting away the covering sheath of the egg or ovum during fertilization. It is synthesised by Golgi complex with the help of its vesicles.

11. **Vitellogenesis.** In oocytes of animals, Golgi apparatus functions as the centre around which yolk is deposited. The process is called vitellogenesis.

12. **Root Hair.** The formation of root hair from their mother cells is believed to take place through the agency of Golgi apparatus.

13. **Formation of Lysosomes.** Some of the vesicles or vacuoles of the Golgi apparatus store digestive enzymes obtained through ER in the inactive state. They form primary lysosomes.

14. **Hypnotoxin.** Hypnotoxin of nematoblasts is formed by Golgi apparatus.

15. **Formation of Plasmalemma.** Membranes of the vesicles produced by Golgi apparatus join in the region of cytokinesis to produce new plasmlemma.

16. **Formation of New Cell Wall.** Pectic compounds of middle lamella and various polysaccharides of the cell wall are secreted by Golgi complex. They are brought to the area of new wall synthesis by secretion vesicles.

3. Lysosomes

They were discovered accidently by a Belgian scientist, Christian de Duve, in 1955 through fractionation technique. The organelles were observed under electron microscope by Novikoff (1956). He also coined the term, lysosomes.

Lysosomes (Gk. *lysis*– digestive or loose, *soma*– body) *are small vesicles which are bounded by a single membrane and contain hydrolytic enzymes in the form of minute crystalline or semicrystalline granules of 5–8 nm.* About 50 enzymes have been recorded to occur in them. All the enzymes do not occur in the same lysosome but there are different sets of enzymes in different types of lysosomes. The important enzymes are acid phosphatases, sulphatases, proteases, peptidases, nucleases, lipases and carbohydrases. They are also called **acid hydrolases** because these digestive enzymes usually function in acidic medium or *p*H of 4–5. Acidic conditions are maintained inside the lysosomes by pumping of H^+ or protons into them. The covering membrane of lysosomes keeps the hydrolytic enzymes out of contact from the cellular contents. It is itself protected from them by high glycosylation of its proteins and lipids. The covering membrane becomes fragile in the absence of the oxygen, or the presence of excess of vitamins A and E, male and female hormones, bile salts, carcinogens, silica, asbestos particles, heat, many drugs, X-rays and ultra-violet rays. The membrane is protected from these agencies by cortisone, cortisol, chloroquine and a type of cholesterol. Lysosomes are called **suicide bags** because of the presence of a large number of digestive enzymes or acid hydrolases in them. Only a thin membrane separates the destructive enzymes from the rest of the cell. If the membrane happens to get broken, the various cellular constituents would undergo lysis.

Lysosomes are generally rounded but can be irregular (*e.g.*, root tip cells) in outline. The diameter varies from 0.2–0.8 μm but sometimes it may grow to a very large size (upto 5 μm in leucocytes, kidney cells, etc.). The interior may be almost solid or differentiated into outer denser region and a central less dense mass with granular content. Lysosomes occur in all animal cells with the exception of red blood corpuscles. In plants and fungi, their function is taken over by vacuoles. In animals, lysosomes are abundant in leucocytes, macrophages, Kupffer's cells and similar cells with phagocytic activity.

Lysosomes are believed to be formed by the joint activity of endoplasmic reticulum

endosomes and Golgi complex (GERL system). The precursors of hydrolytic enzymes are mostly synthesised at the rough endoplasmic reticulum. The latter transfers them to the forming face of Golgi complex either directly or from smooth endoplasmic reticulum through its vesicles. In Golgi complex the precursors are changed to enzymes. The enzymes are then packed in larger vesicles which are pinched off from the maturing face. **Golgian** vesicles are joined by endosomes to produce lysosomes (Machamer, 1993).

Lysosomes do not normally burst in the cytoplasm. All materials which are to be acted upon by lysosome enzymes must enter them. Rather the mateials are usually enclosed inside vacuoles and the vacuoles fuse with the lysosomes for digestion of materials. Lysosomes take part in intracellular digestion of various types of materials of endogenous or exogenous origin. Extracellular digestion can be performed by them under certain conditions. They help in removing various toxic substances including carcinogens.

Lysosomes pass through various stages in the same cell. The phenomenon is called **polymorphism** or existence of more than one morphological form. Depending upon their morphology and function, there are four types of lysosomes— primary, secondary, residual bodies and autophagic vacuoles (Fig. 8.33).

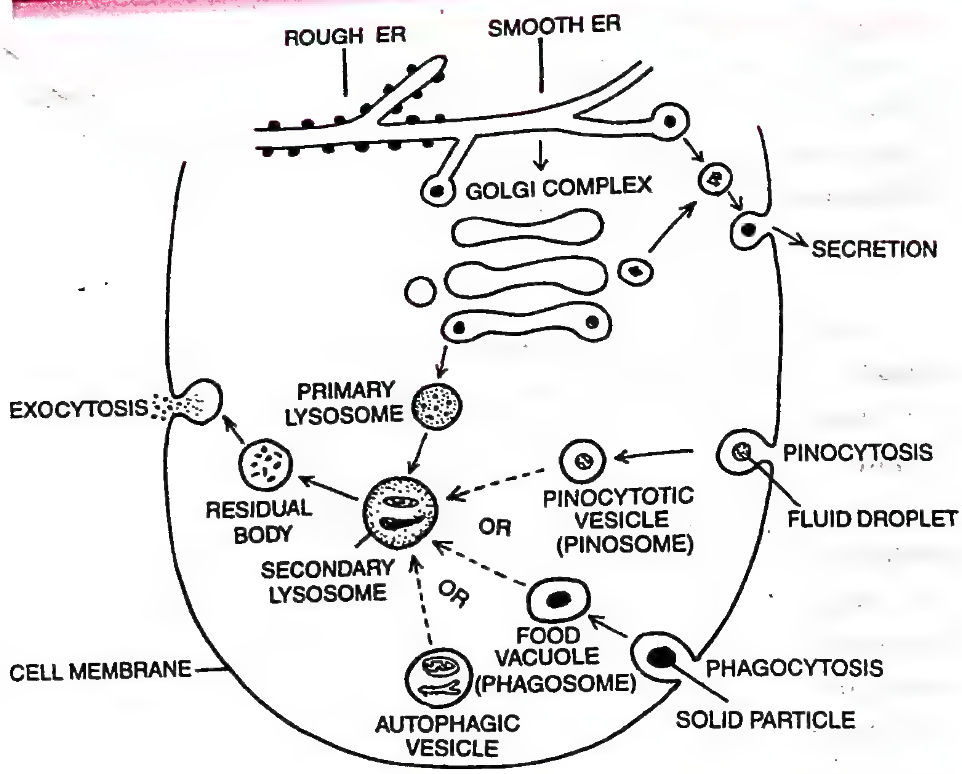


Fig. 8.33. Types of lysosomes and their functions.

1. **Primary Lysosomes.** They are newly pinched off vesicles from the Golgi apparatus which generally fuse with some endosomes to become fully functional. The primary lysosomes are small in size. They contain hydrolytic enzymes in the form of granules.

2. **Secondary Lysosomes.** They are also called **heterophagosomes** or **digestive vacuoles.** A secondary lysosome is formed by the fusion of food containing phagosome with lysosome (having hydrolytic or digestive enzymes). Digestion occurs. The digested food passes out into the cytoplasm. Finally, the secondary lysosome is left with undigested food.

3. **Residual Bodies** (Residual or Tertiary Lysosomes). They are those lysosomes in which only indigestible food materials have been left. The residual bodies or lysosomes pass outwardly and fuse with the plasma membrane to throw out the debris into external environment by **exocytosis** or **ephagy**. Sometimes, residual bodies remain inside the cells due to (i) failure of exocytosis and (ii) absence of some hydrolytic enzymes. This leads to pathological diseases (**storage diseases**) like hepatitis, Pompe's disease, Hurler's disease, Tay-Sachs disease and polynephritis. Ageing is also due to them. Lipofuschin pigment granules are actually residual bodies.

4. **Autophagic Vacuoles** (Autophagosomes, Autolysosomes). They are produced by the fusion of a number of primary lysosomes around worn out or degenerate intracellular organelles. The latter are first wrapped over by one or two membranes from endoplasmic reticulum (Dunn, 1990) before being recognised by lysosomes. The cell debris is digested. The phenomenon is also called **autophagy** or **autodigestion.** It helps in disposal of cell debris. The worn out, aged or injured cells are also disposed of similarly (apoptosis). Therefore, lysosomes are also called **disposal bags** or disposal units. The digested products are made available to the cell for new synthesis. Lysosomes are, therefore, also known as **recycling centres.** Besides removing worn out organelles, old or diseased cells, the autophagic vacuoles are also used in removing internal obstructions. Autophagic vacuoles provide nourishment during starvation (de Duve, 1967).

Autolysis. It is self destruction of a cell, tissue or organ with the help of lysosomes. Lysosomes performing autolysis do not enclose the structures to be broken down. Instead, they themselves burst to release the digestive enzymes. Autolysis occurs in ageing, dead or diseased cells. The disappearance of larval organs during metamorphosis (*e.g.,* tail in frog) is due to autolysis.

Functions

1. **Intracellular Digestion.** Individual cells may obtain food through phagocytosis. The same is digested with the help of lysosomes.

2. **Extracellular Digestion.** For this the lysosomes release enzymes in the external environment through exocytosis.

3. **Body Defence.** Lysosomes of leucocytes devour foreign proteins, toxic substances, bacteria and other microorganisms. They thus take part in natural defence of the body.

4. **Autophagy.** In the metamorphosis of many animals (*e.g.*, amphibians, tunicates) certain embryonic parts like tail, gills, etc. are digested through the agency of lysosomes. The digested food is used in the growth of other parts.

5. **Removal of Obstructions.** Obstructing structures are destroyed by lysosomes.

6. **Mobilisation of Reserves.** During periods of starvation, lysosomes provide nourishment by rapidly hydrolysing the organic foods stored in the cells (carbohydrates, fats and proteins). Hobilisation of reserve food during germination of seeds is also accomplished by lysosomes. Extra nourishment may also be got by digesting some organelles and cells.

7. **Intracellular Scavenging.** In long lived cells the lysosomes perform intracellular scavenging by removing old or useless organelles.

8. **Sperm Lysins.** They are lysosomal enzymes which are used for breaking limiting membrane of eggs.

9. **Disposal of Useless Cells.** They cause breakdown of ageing and dead cells.

10. **Storage Diseases.** In certain regions due to some malfunction, the residual bodies do not undergo exocytosis. Instead, they remain inside the cells and cause disease, *e.g.*, hepatitis, polynephritis.

11. **Formation of Thyroxine.** In thyroid, active hormone thyroxine is formed through hydrolysis of thyroglobulin by the agency of lysosomes.

12. **Cell Division.** Lysosomes seem to be essential for cell division perhaps by overcoming agents that cause repression of mitotic cycle.

13. **Genetic Changes.** They may harm genetic material through the release of nucleases.

It may result in mutations, breakage of chromosomes and other abnormalities. Blood cancer may be result of such an activity.

14. **Carcinogenesis.** Lysosomes remove carcinogens by engulfing and separating them. However, when the carcinogen is in excess, lysosome may harm the living cells as in case of lung fibrosis caused by silicosis or asbestosis.

15. **Leucocyte Granules.** Leucocyte granules are derived from lysosomes.

16. **Osteogenesis.** At the time of formation of bones from cartilage and during remodelling of the bone, lysosomes of the osteoclasts cause breakdown of existing matrix so that it may be replaced by the new one.

4. Vacuoles

Vacuoles are non-cytoplasmic areas present inside the cytoplasm which are separated from the latter by specific membranes. Vacuoles are believed to be formed by expansion and pinching off from ER. Depending upon the contents and functions, vacuoles are of four types— sap vacuoles, contractile vacuoles, food vacuoles and air vacuoles.

(i) **Sap Vacuoles.** They are fluid filled vacuoles or vesicles which are separated from the cytoplasm by a selectively permeable membrane called **tonoplast**. It has a number of transport systems for the passage of different substances. A number of small sap vacuoles occur in animal cells and young plant cells. In mature plant cells, the small vacuoles fuse to form a single large central vacuole which occupies upto 90% of the volume of the cell. The large central vacuole spreads the cytoplasm in the form of a thin peripheral layer. This is a device to facilitate rapid exchange between cytoplasm and the surrounding environment.

The fluid present in the sap vacuoles is often called **sap** or vacuolar sap. It contains mineral salts, sugars, amino acids, esters, proteins, waste products and water soluble pigments called anthocyanins. Some crystalline deposits may also occur. (i) Tonoplast has sites for passage of a number of ions and other materials into vacuole against their concentration gradient. As a result their concentration is quite high in the vacuole as compared to cytoplasm. (ii) They may store food reserve, *e.g.*, sucrose. (iii) Solutes present in cell sap maintain a proper osmotic pressure in the cell for its turgidity and water absorption. (iv) They play an important role in cell enlargement. (v) The sap vacuoles store and concentrate waste products. The same are segregated from the living part of the cell. (vi) Water soluble pigments provide colouration to the cell. The most common water soluble vacuolar pigments are **anthocyanins** (red, blue, purple) and **anthoxanthins** (ivory to deep yellow). They provide colouration to flowers in Rose, Violet, Dahlia, etc. The pigments attract pollinating and dispersing agencies. They also absorb light radiations passing through them so that their intensity is decreased. (vii) Some plant vacuoles have special transport proteins, an acidic *p*H, a battery of hydrolytic enzymes and function as lysosomes. (viii) Tannins are stored in vaculoes, cytoplasm and cell walls. (ix) Latex is stored in vaculoes or vacuolar canals. (x) Alkaloids and tannins stored in vaculoes provide protection against herbivores.

(ii) **Contractile Vacuoles.** They occur in some protistan and algal cells found mostly in fresh water. A contractile vacuole has a highly extensible and collapsible membrane. It is also connected to a few feeding canals (*e.g., Paramecium*). The feeding canals obtain water with or without waste products from the surrounding cytoplasm. They pour the same into the contractile vacuole. The vacuole swells up. The process is called **diastole**. The swollen contractile vacuole comes in contact with plasma membrane and collapses. Collapsing is called **systole**. This throws the vacuolar contents to the outside. Contractile vacuoles take part in osmoregulation and excretion. Osmoregulation is required in fresh water habitats where water has tendency to enter the living cells. Due to the presence of higher osmotic

concentration in the latter, continued entry of water shall cause bursting of the cells. This is prevented by throwing the extra water to the outside with the help of contractile vacuoles.

(iii) **Food Vacuoles.** They occur in the cells of protozoan protists, several lower animals and phagocytes of higher animals. A food vacuole is formed by fusion of phagosome and a lysosome. The food vacuole contains digestive enzymes with the help of which nutrients are digested. The digested materials pass out into the surrounding cytoplasm.

(iv) **Air Vacuoles** (Pseudovacuoles, Gas vacuoles). They have been reported only in prokaryotes. An air vacuole is not a single entity, neither it is surrounded by a common membrane. It consists of a number of smaller submicroscopic vesicles. Each vesicle is surrounded by a protein membrane and encloses metabolic gases. Air vacuoles not only store gases but provide buoyancy, mechanical stength and protection from harmful radiations.

MITOCHONDRIA

Mitochondria are cell organelles of aerobic eukaryotes which take part in oxidative phosphorylation and Krebs cycle of aerobic respiration. They are called **power houses of cell** because they are the major centres of release of energy in the aerobic respiration. They were first observed by Kolliker in 1880. Benda (1897) gave the present name of mitochondria (Gk. *mitos*– thread, *chondrion*– grain) to the organelles. Mitochondria can be stained differentially with Janus Green and are easily distinguishable under light microscope though ultrastructure can be studied only under electron microscope.

Mitochondria are absent in prokaryotes and anaerobic eukaryotes. Mitochondria are secondarily lost in the red blood corpuscles of mammals. Their number varies from one to several. The number depends upon cellular activities. Cells of dormant seeds have very few mitochondria. Those of germinating seeds have several mitochondria. In general green plant cells contain less number of mitochondria as compared to nongreen plant cells and animal cells.

The position of mitochondria in a cell depends upon the requirement of energy and amino acids. In unspecialised cells they are randomly distributed throughout the cytoplasm. In absorptive and secretory cells, they lie in the peripheral cytoplasm. During nuclear division, more of mitochondria come to lie around the spindle. Mitochondria are more abundant at the bases of cilia or flagella to provide them energy for movements. In muscle fibres they occur in rows in the regions of light bands in between the contractile elements.

Shape and Size

Commonly mitochondria are cylindrical in outline. The size of the mitochondria is variable. Normally, they have a length of 1.0–4.1 μm and a diameter of 0.2–1.0 μm (average 0.5 μm).

Chemical Composition. **Proteins.** 60–70%, **Lipids** 25–35%, **RNA** 5–7%, **DNA.** Small quantity. **Minerals.** Traces, Granules Manganese and Calcium phosphate.

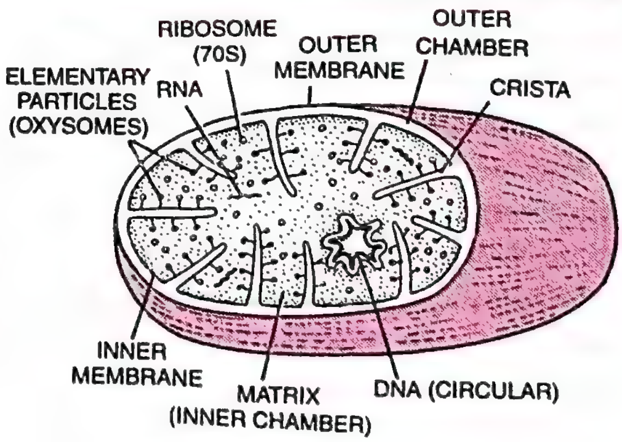


Fig. 8.34. Structure of a mitochondrion. A, mitochondrion partly cut open to show internal and external structure.

Ultrastructure

A mitochondrion contains two membranes and two chambers, outer and inner (Fig. 8.34). The two membranes form the envelope of the mitochondrion. Each of them is 60–75Å in thickness.

Outer Membrane. The membrane is smooth. It is permeable to a number of metabolites. It is due to presence of protein channels called porins or minute pores. A few enzymes connected with lipid synthesis are located in the membrane. It is poorer in proteins as compared to inner membrane.

Inner Membrane. It is permeable to only some metabolites. It is rich in double phospholipid called cardiolipin (having four fatty acids) which makes the membrane impermeable to ions. Protein content is also high, being 70–75% of total components. The inner membrane is infolded variously to form involutions called **cristae**. They are meant for increasing the physiologically active area of the inner membrane. The cristae are generally arranged like baffles, at right angles to the longitudinal axis of the mitochondrion. They are tubular (most plant cells) or plate like (most animal cells) or vesicle-like (*e.g., Euglena*). A crista encloses a space that is continuation of the outer chamber. The density of cristae indicates the intensity of respiration.

The inner membrane as well as its cristae possess small tennis-racket like particles called **elementary particles,** $F_0 - F_1$ particles or oxysomes (= oxisomes). A mitochondrion contains $1\times10^4 - 1 \times 10^5$ elementary particles (Fig. 8.35 A). Each elementary particle, $F_0 - F_1$ particle or oxysome has a head, a stalk and a base (Fig. 8.35 B). The base (F_0 subunit) is about 11 nm long and 1.5 nm in thickness. The stalk is 5 nm long and 3.5 nm broad. The head (F_1 subunit) has diameter of 8.5 nm. Elementary particles function as ATP-ase. They are, therefore, the centres of ATP synthesis during oxidative phosphorylation. Both head and stalk constitute F_1. F_0 or base has a roter and a stator. A channel occurs between roter and stator for passage of protons (H^+). Stator is connected to head region by an arm. Enzymes of electron transport are located in the inner membrane in contact with elementary particles.

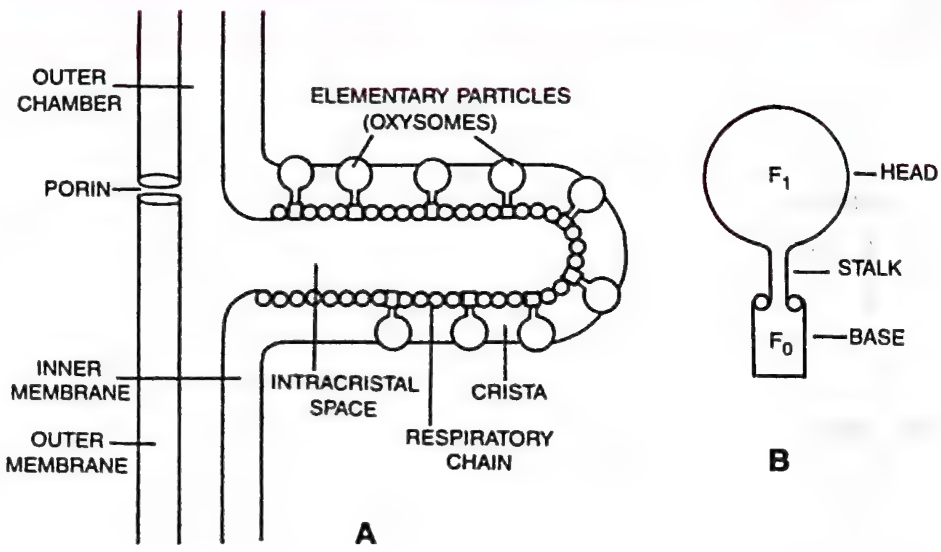


Fig. 8.35. A, inner membrane with elementary particles. B, elementary particle.

At places, outer and inner mitochondrial membranes come in contact. They are called **adhesion sites.** Adhesion sites are special permeation regions of the mitochondrion for transfer of materials from outside to inside and *vice versa.*

Outer Chamber (Peri-mitochondrial Space). The chamber is the space that lies between the outer and inner membrane of the mitochondrial envelope. Usually, it is 60–100 Å wide. It extends into the spaces of the cristae (Fig. 8.35 A). The chamber contains a fluid having a few enzymes.

Inner Chamber. It forms the core of the mitochondrion. The inner chamber contains a semi-fluid **matrix.** The matrix has protein particles, ribosomes, RNA, DNA (mitochondrial or mDNA), enzymes of Krebs or TCA cycle (except succinate dehydrogense which is

membrane based), amino acid synthesis and fatty acid metabolism, crystals of calcium phosphate and manganese. Mitochondrial ribosomes are 55 S to 70 S in nature. They thus resemble the ribosomes of prokaryotes. DNA is naked. It is commonly circular but can be linear. DNA makes the mitochondrion semi-autonomous.

Differences between Outer and Inner Mitochondrial Membranes

Outer Mitochondrial Membrane	*Inner Mitochondrial Membrane*
1. The membrane is smooth.	1. It contains a number of particles.
2. It bears porins or protein lined channels.	2. It bears carrier and other transport proteins.
3. Enzymes are fewer.	3. It contains a number of enzymes.
4. Foldings are absent.	4. Inner mitochondrial membrane develops a large number of infoldings called cristae.
5. Protein content is roughly equal to that of lipids.	5. Protein content is quite high (upto 80%) while lipid content is low.
6. Cholesterol and other lipids are present. Cardiolipins are absent.	6. Cardiolipins occur.
7. Electron transport system (ETS) is absent.	7. ETS present in inner membrane.
8. It is permeable to most biochemicals.	8. It is selectively permeable.

Autonomy of Mitochondria

Mitochondria show a large degree of autonomy or independence in their functioning.

1. Mitochondria have their own DNA which can replicate independently.
2. Mitochondrial DNA produces its own mRNA, tRNA and rRNA.
3. The organelles possess their own ribosomes.
4. Mitochondria synthesise some of their own structural proteins. However, most of the mitochondrial proteins are synthesised under instructions from cell nucleus.
5. The organelles synthesise some of the enzymes required for their functioning.
6. They grow internally.
7. New mitochondria develop by division/binary fission of pre-existing mitochondria.

However, mitochondria are not fully autonomous. Both their structure and functioning are partially controlled by nucleus of the cell and availability of materials from cytoplasm. Mitochondria are believed to be symbionts (Margulis, 1971) in the eucaryotic cells which became associated with them quite early in the evolution.

Functions

1. Mitochondria are miniature biochemical factories where food stuffs or respiratory substrates are completely oxidised to carbon dioxide and water. The energy liberated in the process is initially stored in the form of reduced coenzymes and reduced prosthetic groups. The latter soon undergo oxidation and form energy rich ATP. ATP comes out of mitochondria and helps perform various energy requiring processes of the cell like muscle contraction, nerve impulse conduction, biosynthesis, membrane transport, cell division, movement, etc. Because of the formation of ATP, the mitochondria are called **power houses** of the cell.

2. Mitochondria provide important intermediates for the synthesis of several biochemicals like chlorophyll, cytochromes, pyrimidines, steroids, alkaloids, etc.

3. The matrix or inner chamber of the mitochondria has enzymes for the synthesis of fatty acids. Enzymes required for the elongation of fatty acids have been reported in the outer mitochondrial chamber.

4. Synthesis of many amino acids occurs in the mitochondria. The first formed amino acids are glutamic acid and aspartic acid. They are synthesised from a-ketoglutaric acid and oxaloacetic acid respectively. Other amino acids are produced by transformation and transamination or transfer of amino group (—NH_2) from glutamic acid and aspartic acid.

5. Mitochondria may store and release Calcium when required.

6. An organism generally receives mitochondria from its mother (maternal inheritance).

PLASTIDS

The term plastid was introduced by E. Haeckel in 1866. *Plastids are semi-autonomous organelles having DNA and double membrane envelope which store or synthesise various types of organic compounds.* With the exception of some protistans, (*e.g.*, *Euglena*, dinophyceae, diatoms) plastids are restricted to plants only. Plastids develop from colourless precursors called **proplastids**. Proplastids have the ability to divide and differentiate into various types of plastids. Depending upon their colour, plastids are of three main types— leucoplasts, chromoplasts and chloroplasts (Schimper, 1883).

(i) **Leucoplasts** (Gk. *leucos*– white, *plastos*– moulded). They are colourless plastids which generally occur near the nucleus in nongreen cells and possess internal lamellae. Grana and photosynthetic pigments are absent. Leucoplasts have variable size and form, *e.g.*, rounded, oval, cylindrical, filamentous, etc. There are three types of special leucoplasts. (a) **Amyloplasts**. They are the starch containing leucoplasts. An amyloplast is several times larger than the original size of leucoplast. It contains a simple or compound starch grain covered by a special protein sheath, *e.g.*, Potato tuber, Rice, Wheat. (b) **Elaioplasts** (Lipidoplasts, Oleoplasts). The colourless plastids store fat, *e.g.*, Tube Rose. (c) **Aleuroplasts, Proteoplasts** or **Proteinoplasts**. The plastids contain protein in the amorphous, crystalloid or crystallo-globoid state (*e.g.*, aleurone cells of Maize grain, endosperm cells of Castor).

(ii) **Chromoplasts** (Gk. *chroma*– colour, *plastos*– moulded). The plastids are yellow or reddish in colour because of the presence of carotenoid pigments. Chlorophylls are absent. Chromoplasts are formed either from leucoplasts or chloroplasts. Lamellae degenerate partially or completely during chromoplast formation. Change of colour from green to reddish during the ripening of Tomato and Chilli is due to transformation of chloroplasts to chromoplasts. The orange colour of Carrot roots is due to chromoplasts. The pigments are often found in crystallised state so that the shape of the plastids can be like needles, spindles or irregular. (i) Chromoplasts provide colour to many flowers for attracting pollinating insects. (ii) They provide bright red or orange colour to fruits for attracting animals for dispersal. (iii) They are also the site of synthesis of membrane lipids.

(iii) **Chloroplasts** (Gk. *chloros*– grass green, *plastos*– moulded). They are greenish plastids which possess photosynthetic pigments, chlorophylls and carotenoids, and take part in the synthesis of food from inorganic raw materials in the presence of radiation energy. Chloroplasts of algae other than green ones are called **chromatophores** (*e.g.*, **rhodoplasts** of red algae, **phaeoplasts** of brown algae).

Differences between Leucoplasts and Chromoplasts	
Leucoplasts	*Chromoplasts*
1. They are colourless plastids.	1. Chromoplasts are orange-red plastids.
2. Leucoplasts usually occur in unexposed parts of plants.	2. They are commonly found in exposed parts like flowers and fruits.
3. Internal lamellae are present.	3. Internal lamellae degenerate.
4. They take part in storage of various substances like starch (amyloplasts), fat (elaioplasts) and protein (aleuroplasts).	4. Chromoplasts are rich in carotenoid and lipids.
5. The shape is more regular, mostly rounded.	5. The shape is irregular and having angles due to crystallisation of pigments.
6. They can change to other types of plastids.	6. They do not get changed to other types.
7. Leucoplasts do not attract animals as they are colourless.	7. Being coloured, chromoplasts attract animals for pollination and fruit dispersal.

Number. The number of chloroplasts per cell of algae is usually fixed for a species. The minimum number of one chloroplast per cell is found in green alga *Ulothrix* and several species of *Chlamydomonas*. However, different species of a genus may have different number of chloroplasts, *e.g.*, 1 in *Spirogyra indica* and 16 in *S. rectospora*. A photosynthetic leaf chlorenchyma cell has 20–40 chloroplasts. An internodal cell of *Chara* (an alga) has several hundred chloroplasts.

Shape. In algae the chloroplasts have various shapes. They may be plate like (*e.g.*, *Ulothrix*), cup-shaped (*e.g.*, *Chlamydomonas*), ribbon-like (*e.g.*, *Spirogyra*), polygonal or stellate (*e.g.*, *Zygnema*) and reticulate (*e.g.*, *Oedogonium*). The chloroplasts of higher plants are generally disc-shaped with oval or circular outline. Rarely, they may be lens-shaped, rounded or club-shaped.

Size. Like shape, the size of the chloroplasts is different in different species. The discoid chloroplasts of higher plants are 4–10 μm in length and 2–4 μm in breadth. The size is generally larger in case of polyploid cells as compared to diploid and haploid cells. Normally it is much smaller than that of the cell. However, in many algae the chloroplast may occupy almost the whole length of the cell, *e.g.*, *Spirogyra*. The chloroplast of *Spirogyra* may reach a length of 1 mm.

Chemical Composition. Protein– 50–60%. Lipids– 25–30%. Chlorophyll– 5–10%. Carotenoids (carotenes and xanthophylls)– 1–2%. DNA– upto 0.5%. RNA– 2–3%. Vitamins K and E, quinones, Mg, Fe, Co, Mn, P, etc.– in traces.

Ultrastructure (Fig. 8.36–8.37)

A chloroplast has three parts— envelope, matrix and thylakoids. Pyrenoid and stigma are two additional structures present in the chloroplasts of some algae.

Chloroplast Envelope. A chloroplast is covered by an envelope made up of two smooth membranes. Each membrane is about 90–100 Å thick. It has trilaminar lipoprotein structure. The two membranes are separated by an **intermembrane space** of 100–200 Å width. The outer membrane may be attached to endoplasmic reticulum. At places the inner membrane is connected to thylakoids. As in mitochondria, the outer membrane is more permeable than the inner membrane. The inner membrane has more of proteins including carrier proteins.

Matrix. The ground substance of a chloroplast is known as **matrix** or **stroma**. It is semifluid colloidal complex that is made of 50% soluble proteins. The remaining is DNA,

RNA, ribosomes, plasto-globuli and enzymes. Chloroplast or cpt DNA is naked, circular or occasionally linear. A chloroplast may have several copies of it. DNA makes the chloroplast genetically autonomous because it can both replicate and transcribe to form RNA. Chloroplast ribosomes are 70 S. They resemble the ribosomes of prokaryotes. With the help of ribosomes the chloroplast is able to synthesize most of the enzymes required by it. The important enzymes present in chloroplast are those that take part in synthesis of photosynthetic pigments, photolysis of water, photophosphorylation, dark assimilation of CO_2, synthesis and degradation of starch, synthesis of lipids, etc. Plastoglobuli are lipid droplets of 10–500 nm diameter. They may contain some enzymes, vitamin K and quinones. The chloroplast matrix of higher plants may store starch temporarily, as starch grains. It is known as **assimilation starch**. In green algae (*e.g.*, *Spirogyra, Ulothrix*), the chloroplasts possess special starch storing structures called **pyrenoids**.

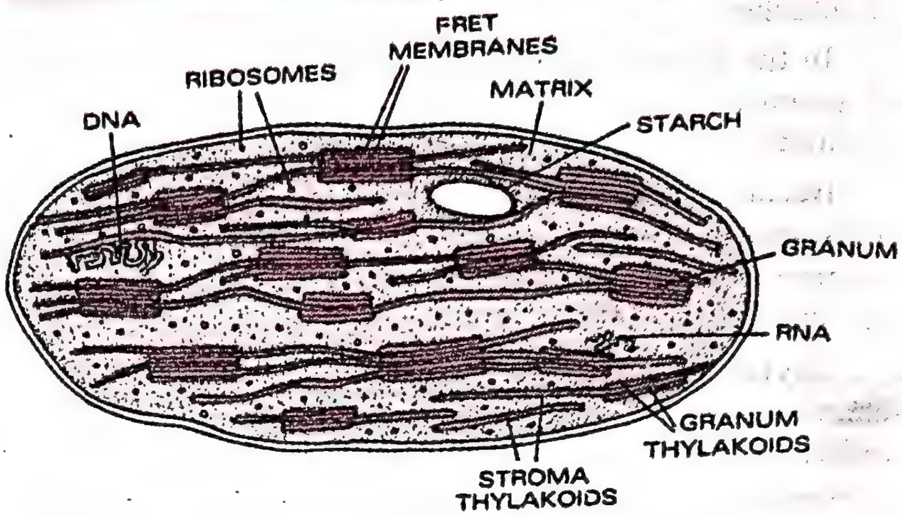


Fig. 8.36. Internal structure of chloroplast of higher plants as seen under electron microscope.

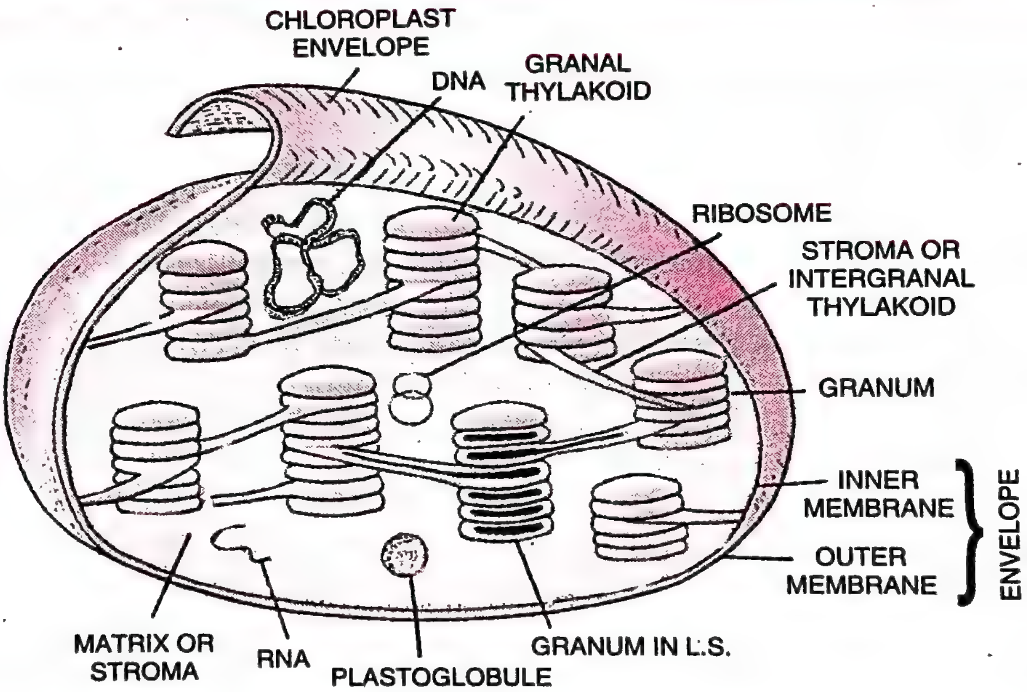


Fig. 8.37. Schematic 3-dimensional structural diagram of a chloroplast.

Thylakoids (Menke, 1961). They are membrane lined flattened sacs which run throughout the stroma or matrix of the chloroplast. Since, they take part in photosynthesis, they are also called photosynthetic thylakoids. Thylakoids are thus the **structural elements** of the

chloroplast. They generally run parallel but may show interconnections. Thylakoids may also be attached to the inner membrane of chloroplast envelope.

In the chloroplasts of higher plants, thylakoids are stacked at places to form grana. 40–60 grana may occur in a chloroplast. Each granum has 2–100 thylakoids. Grana are absent in bundle sheath and algal chloroplasts. The latter are, therefore, **agranal.**

Because of the presence of grana, thylakoids are differentiated into two— granal thylakoids and stroma or intergranal thylakoids. A granum is attached to only a few stroma or nongranal thylakoids, though it is made up of upto 100 thylakoids. It is, therefore, believed that the thylakoids get folded and bifurcated in the region of grana.

Thylakoid membranes possess photosynthetic pigments and coupling factors. Coupling factors are involved in ATP synthesis. Photosynthetic pigments include chlorophyll *a*, chlorophyll *b*, carotenes and xanthophylls. They occur in specific groups called photosystems (previously quantasomes). There are two photosystems, I and II. Photosystem II occurs in appressed parts of granal thylakoids while photosystem I is found in stromal thylakoids and nonappressed parts of granal thylakoids.

Functions

1. **Photosynthesis.** Chloroplasts are the centres of photosynthesis or formation of organic compounds from inorganic raw materials. The organic substances, thus synthesised, not only provide body building material to autotrophic plants themselves but also to all heterotrophic plants as well as animals.

2. **Energy Transduction.** Chloroplasts are able to trap sun energy and change it into chemical energy. The chemical energy is used by all living organisms to perform their life activities.

3. **Consumption of Carbon Dioxide.** Chloroplasts pick up carbon dioxide and use the same in photosynthesis. This keeps the percentage of this gas balanced in the atmosphere as carbon dioxide is being constantly added to it through combustion and respiration.

4. **Liberation of Oxygen.** Chloroplasts liberate oxygen which is passed into the atmosphere. This keeps the balance of oxygen constant in the atmosphere, as oxygen is being consumed in respiration and combustion.

5. **Storage of Starch.** They store starch either temporarily (in higher plants) or permanently (in several algae).

6. **Photosensitivity.** Chloroplasts of some algae provide photosensitivity because of the presence of stigma or eye spot.

7. **Reducing Power.** The reducing power produced during light reaction (NADPH) is used in the reduction of nitrate and synthesis of amino acids.

8. **Synthesis of Fatty Acids.** Murphy and Leech (1978) have reported the synthesis of fatty acids in Spinach chloroplasts.

9. **Storage of Lipids.** Chloroplasts store fat in the form of plastoglobuli.

10. **Formation of Chromoplasts.** They can be changed into the chromoplasts to provide colour to many flowers and fruits for attracting animals.

Autonomy

Though chloroplasts are under the overall control of the nucleus of the cell, they possess a great degree of functional autonomy : (i) A chloroplast has its own DNA. The DNA is naked. It can show both replication and transcription (or produce RNA). (iii) The plastid manufactures some of its own proteins, enzymes and other biochemicals because of the presence

of 70 S ribosomes which can help translate the coded information contained in mRNAs transcribed over chloroplast DNA. (iii) New chloroplasts arise either from division of pre-existing ones or the division of their precursors known as proplastids.

Similarities and dissimilarities between Mitochondria and Chloroplasts

Similarities

(1) Presence of double membrane envelope. (2) Formation of involutions from the inner membrane. (3) Both are semi-autonomous. (4) The organelles possess their own DNA, RNA and 70s ribosomes to have sufficient functional independence from the cellular machinery. cpt DNA is bigger than mt DNA. However, genetic information contained in these DNAs is limited. (5) DNA is naked in both. (6) They are formed by the division of pre-existing organelles. (7) They take part in energy transduction. (8) The organelles produce ATP. (9) Both of them can form fatty acids as well as amino acids. (10) Both occcur in eukaryotes and are absent in prokaryotes. (11) They are believed to be procaryotic symbionts.

Dissimilarities

Mitochondria	*Chloroplasts*
1. They are colourless cell organelles.	1. Chloroplasts are green organelles.
2. Mitochondria are found in all types of aerobic cells, both plants and animals.	2. They are restricted to only some protists and exposed cells of plants.
3. They are generally cylindrical in outline.	3. Chloroplasts are generally disc-shaped.
4. Their inner membrane is thrown up into folds called cristae.	4. The inner membrane gives rise to flattened sacs called thylakoids.
5. Cristae remain in contact with inner membrane.	5. Thylakoids usually break connection with the inner membrane.
6. Cristae do not form grana.	6. At places thylakoids produce grana.
7. Pigments do not occur in mitochondria.	7. The membranes of thylakoids possess chloroplylls and carotenoids.
8. Inner membrane and its cristae possess a large number of elementary particles for ATP synthesis.	8. ATP synthesis is carried out by coupling factors present only on the thylakoids.
9. Mitochondria do not take part in the conversion of light energy into chemical energy.	9. Chloroplasts are the centres of conversion of solar energy into chemical energy.
10. They liberate energy by breaking down of organic food.	10. They store energy by building up organic food.
11. Organic food is broken down to produce carbon dioxide and water.	11. Carbon dioxide and water are used as raw materials for synthesis of organic food in the process of photosynthesis.
12. Mitochondria consume oxygen.	12. Chloroplasts liberate oxygen.

Sphaerosomes or Oleosomes

Sphaerosomes (= spherosomes) *are small cell organelles bounded by single membrane which take part in storage and synthesis of lipid*. They were discovered by Perner in 1953. Sphaerosomes are small spherical and refractile vesicles which are 0.5–1.0 μm in diameter. They arise from endoplasmic reticulum (Harwood, 1997) and are surrounded by a single but **half unit membrane** with phospholipid monolayer having polar heads towards the cytosol and hydorphobic tails towards the inner side. The membrane is stabilised by proteins called **oleosins** (Buchanan *et al*, 2000). 98% of a sphaerosome is lipid. Proteins constitute the

remaining 2%. Some proteins are probably enzymatic and take part in the synthesis of lipids. Because of the presence of lipids, sphaerosomes can be seen under light microscope after staining the cells with Sudan dyes and osmium tetraoxide. Sphaerosomes occur abundantly in the endosperm cells of oil seeds. Sphaerosomes of some tissues (*e.g.*, tobacco endosperm, maize root tip) contain hydrolytic enzymes. Therefore, they are considered to have lysosomic activity.

MICROBODIES (Rhodin, 1954)

They are small cell organelles bounded by single membrane which absorb molecular oxygen and take part in oxidations other than those involved in respiration. Microbodies are of two types— peroxisomes and glyoxysomes.

(i) **Peroxisomes.** *They are microbodies which contain enzymes for peroxide biosynthesis.* Peroxisomes were discovered by De Duve *et al* (1965) with the help of fractionation technique. The term was coined by De Duve in 1969. Peroxisomes are found in both plant and animal cells, generally in close association with endoplasmic reticulum, mitochondria and chloroplasts. Despite absence of DNA, peroxisomes are believed to be able to replicate like mitochondria and plastids (Waterham and Craig, 1997). They are believed to vestige of an ancient organelle present in protoeucaryotes which performed all oxidation reactions prior to evolution of mitochondria. They contain special docking proteins called **peroxins** for obtaining materials from cytosol and endoplasmic reticulum. Peroxisomes occur in all eucaryotic cells. They are quite abundant in liver and kidney cells. A photosynthetic cell may have 70–100 peroxisomes. Peroxisomes are believed to develop from endoplasmic reticulum. Their size and shape are variable. Commonly the peroxisomes have a diameter of 0.5–1.0 μm. They are covered over by a single membrane. The interior contains a matrix which may be granular or have fibrils arranged variously. In some cases the matrix has a central dense, crystalline or fibrous core which is called **nucleoid.**

The peroxisomes contain oxidative enzymes like urate oxidase, D-amino acid oxidase, α-hydroxy acid oxidase and β-hydroxy acid oxidase. Molecular oxygen is required. The reactions produce hydrogen peroxide which is immediately metabolised by another enzyme called catalase.

(a) In animal cells, peroxisomes metabolise in number of toxic substances like nitrite, phenols, formaldehyde, formic acid, methanol, ethanol etc. 25% of alcohol consumed by a person is detoxified by peroxisomes inside liver cells.

(b) Unusual substances or **xenobiotics** (*e.g.*, D-aminoacids, alkanes) which cannot be metabolised by normal enzymes are broken down inside peroxisomes.

(c) Urate produced during catabolism of nucleic acids and some proteins is changed into allantoin inside peroxisomes.

(d) Long chain (*e.g.*, prostaglandins) and branched chain fatty acids are initially broken down by peroxisomes.

(e) In root nodules, they convert fixed nitrogen into ureids for transport (Atkins, 1991).

(f) Plant peroxisomes found in photosynthetic cells, perform **photorespiration**. For this, they are associated with chloroplasts and mitochondria. Peroxisomes pick up glycolate from chloroplasts. The same is oxidised with the help of oxygen to produce glyoxylate. Hydrogen peroxide is formed as byproduct. Glyoxylate is changed to amino acid glycine. The glycine condenses to produce amino acid serine and carbon dioxide.

(ii) **Glyoxysomes** (= Glyoxisomes; Briedenbach, 1967, Fig. 8.38). *Glyoxysomes are microbodies which contain enzymes for β-oxidation of fatty acids and glyoxylate pathway.*

They are considered to be special peroxisomes. The microbodies appear transiently in germinating oil seeds and the cells of some fungi till the stored fat is consumed. Like other microbodies, glyoxysomes have a single covering membrane and an enzyme rich matrix with a crystalloid core. β-oxidation of fatty acids produces acetyl CoA. The latter is metabolised in glyoxylate cycle to produce carbohydrates. After completion of their function, glyoxysomes are believed to be changed into peroxisomes. They reappear in senescent plant tissues for degradation of lipids and mobilisation of degradation products.

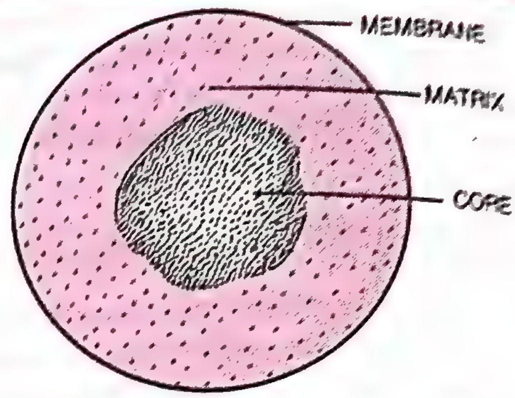


Fig. 8.38. Structure of glyoxysome.

RIBOSOMES (Palade Particles)

Ribosomes were discovered by Robinson and Brown (1953) in plant cells and by Palade (1955) in animal cells. Palade (1955) also coined the term of ribosome. A large number of ribosomes occur in a cell. For example, a single cell of bacterium *Escherichia coli* contains 20000–30000 ribosomes. Their number in eucaryotic cells is several times more. *Ribosomes are naked ribonucleoprotein protoplasmic particles (RNP) with a length of 200–340 Å and diameter of 170–240Å which function as the sites for protein or polypeptide synthesis.* Ribosomes are popularly known as **protein factories**. They are subspherical in outline. A covering membrane is absent. Each ribosome consists of two unequal subunits, larger dome shaped and smaller oblate-ellipsoid. The large subunit has a protuberance, a ridge and a stalk. The smaller subunit possesses a platform, cleft, head and base. It is about half the size of larger subunit. The smaller subunit fits over the larger one at one end like a cap (Fig. 8.40). Mg^{2+} is required for binding the two subunits (Below 0.0003 M or 0.3 mM Mg^{2+} the two subunits dissociate while above this strength the ribosomes can come together to form dimers Fig. 8.39).

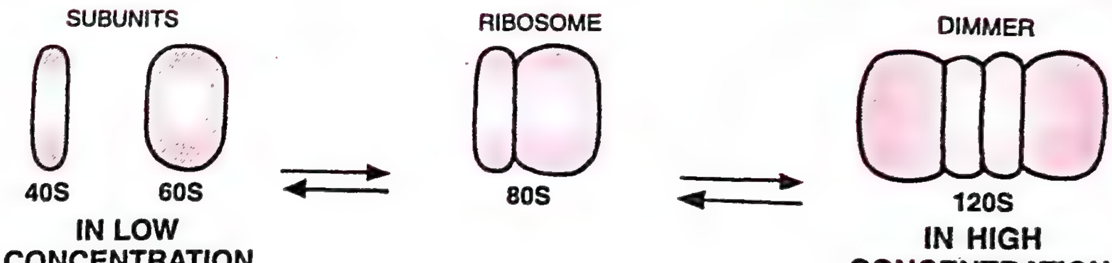


Fig. 8.39. Diagram to illustrate the effect of Mg concentration on ribosome.

Ribosomes may occur singly as **monosomes** or in rosettes and helical groups called **polyribosomes** (Rich, 1963) or **polysomes** (Gk. *poly*– many, *soma*– body). The different ribosomes of a polyribosome are connected with a 10–20 Å thick strand of messenger or mRNA (Fig. 8.41) The maintenance of polyribosome requires energy. Polyribosomes are formed during periods of active protein synthesis when a number of copies of the same polypeptide are required.

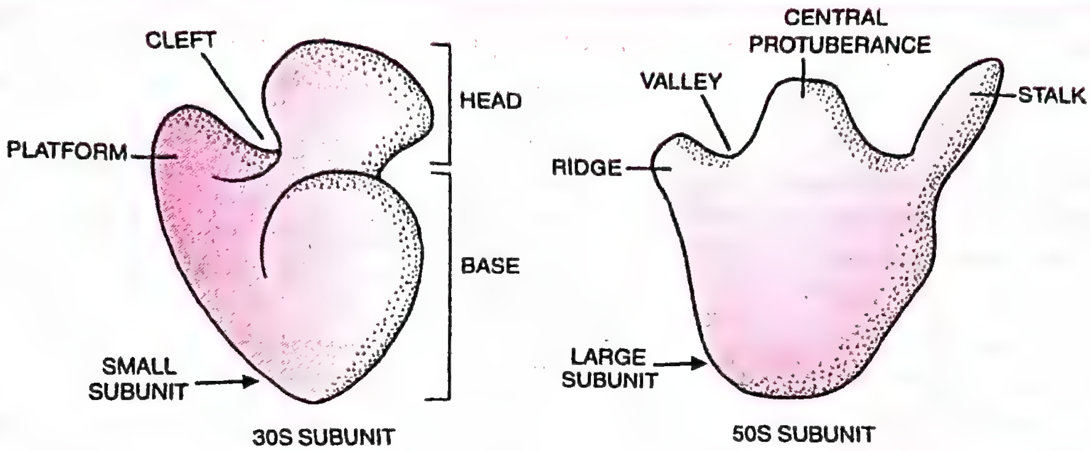


Fig. 8.40. Parts of ribosome.

Ribosomes occur in all living cells with the exception of mammalian erythrocytes or red blood corpuscles. Depending upon the place of their occurrence, ribosomes are of two types, cytoplasmic and organelle. The organelle ribosomes are found in plastids (plastidoribosomes) and mitochondria (mitoribosomes). The cytoplasmic ribosomes (cytoribosomes) may remain free in the cytoplasmic matrix or attached to the cytosolic surface of endoplasmic reticulum with the help of a special ribophorin or SRP protein. Attachment occurs through larger or 60 S subunits. Different types of ribosomes may produce different types of proteins, *e.g.*, structural proteins from free cytoplasmic ribosomes and globular proteins from ribosomes bound to ER. The bound ribosomes generally transfer their proteins to cisternae of the endoplasmic reticulum for transport to other parts both inside and outside the cell. They are also sent to intracellular organelles like nucleus, mitochondria and chloroplasts. Newly synthesised proteins are assisted in their folding and transport by specific proteins called **chaperones.**

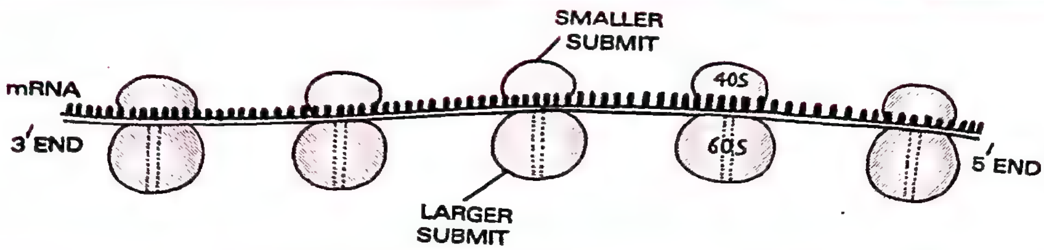


Fig. 8.41. Polyribosome.

The size of the ribosomes is determined by sedimentation coefficient in the centrifuge. It is measured as Svedberg unit called S (S $=1 \times 10^{-13}$ sec). The cytoplasmic ribosomes of eucaryotes are 80 S. They have a size of 300–340 Å× 200–240 Å and mass of 4.0–4.5 million daltons. The cytoplasmic ribosomes of procaryotes (PPLO, bacteria, blue-green algae) are 70 S. The size is 200–290 Å × 170–210 Å and mass is 2.7–3.0 million daltons (Fig. 8.42). The organelle ribosomes are also 70 S but in mammalian mitochondria they have sedimentation coefficient of 55 S. The two subunits of **80 S ribosomes** are 60S and 40S while **70S ribosomes** have 50S and 30 S subunits. A tunnel occurs between the two subunits for passage of mRNA. The larger subunit has a groove for pushing out the newly synthesised polypeptide.

A ribosome has four sites for specific attachments. (i) mRNA binding site. (ii) A or amminoacyl site for binding to newly arrived aminoacid carrying tRNA. (iii) P or peptidyl site with tRNA carrying growing polypeptide. (iv) E or exit site for freed tRNA before it leaves the ribosome.

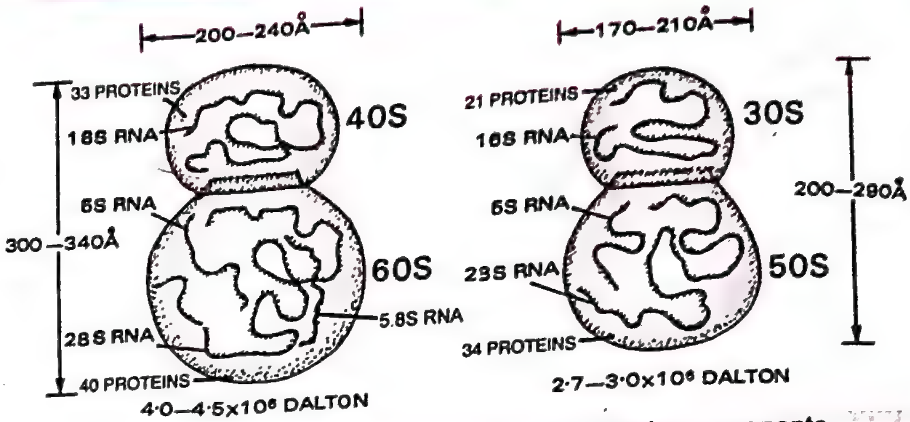


Fig. 8.42. 80S and 70S Ribosomes and their components.

80S ribosomes are synthesised inside the nucleolus. Proteins come from cytoplasm. 5S RNA is synthesised separately while others are formed by the nucleolus. 80S ribosomes do not become functional inside the nucleolus. Their subunits come out of the nucleus and become operational in cytoplasm. 70S ribosomes of procaryotes are formed in the cytoplasm while those of semi-autonomous cell organelles are formed in their matrix.

Chemically a ribosome is made of two parts, proteins and rRNA. The ribosomes of liver cells may also contain lipids to the extent of 5–10%. Usually more rRNA is present in 70S ribosomes as compared to protein (60–65 : 35–40) while the reverse is true for 80S ribosomes (40–44 : 56–60). 40S subunit of 80S ribosome contains 33 protein molecules and a single 18S rRNA. 30S subunit of 70S ribosome possesses 21 protein molecules and 16S rRNA. 60S subunit of 80S ribosome has 40 protein molecules and three types of rRNAs— 28S, 5.8S and 5S. 50S subunit of 70S ribosome contains 34 protein molecules and two types of rRNAs— 23S and 5S. Proteins are both structural and enzymatic.

Functions. (i) *Protein Factories.* Ribosomes are sites for polypeptide or protein synthesis. (ii) *Free and Attached Ribosomes.* Free ribosomes synthesise structural and enzymatic proteins for use inside the cell. The attached ribosomes synthesise proteins for transport. (iii) *Enzymes and Factors.* Ribosomes provide enzymes (*e.g.*, Peptidyl transferase) and factors for condensation of amino acids to form polypeptide. (iv) *rRNA.* Ribosome contains rRNAs for providing attaching points to mRNA and tRNAs. (v) *mRNA.* Ribosome has a tunnel for mRNA so that it can be translated properly. (vi) *Protection.* Newly synthesised polypeptide is provided protection from cytoplasmic enzymes by enclosing it in the groove of larger subunit of ribosome till it attains secondary structure.

Differences between 80S and 70S Ribosomes

80S Ribosomes	*70S Ribosomes*
1. They occur only in eucaryotic cells.	1. 70S ribosomes are found both in procaryotes and eucaryotes.
2. They occur inside the cytoplasm of eukaryotes either freely or attached to ER.	2. The ribosomes are found freely inside the cytoplasm of prokaryotes and matrix of plastids and mitochondria of eukaryotes.
3. The ribosomes are larger in size with a length of (300—340 Å) and breadth (200—240 Å).	3. They are comparatively smaller with a length of (200—290 Å) and a diameter of (170—210 Å).
4. The sedimentation co-efficient is 80.	4. The sedimentation coefficient is 70.

5. They are comparatively heavier, 4.0—4.5 million daltons.	5. 70S ribosomes are comparatively lighter, 2.7—3.0 million daltons.
6. The two subunits are 40S and 60S.	6. The two subunits are 30S and 50S.
7. The rRNAs of 80S ribosomes are 28S + 5.8S + 5S in larger subunit and 18S in smaller subunit.	7. The rRNAs of 70S ribosomes are 23S + 5S (larger subunit) and 16S (smaller subunit).
8. The ribosomes possess less of rRNA as compared to protein (40 : 60).	8. The ribosomes contain more of rRNA than protein (60 : 40).
9. 80S ribosomes are synthesised inside the nucleolus.	9. 70S ribosomes are synthesised in the cytoplasm of procaryotes and matrix of semi-autonomous cell organelles.
10. It contains about 73 protein molecules, 40 in larger subunit and 33 in smaller subunit.	10. It possesses about 55 protein molecules, 34 in larger subunit and 21 in smaller subunit.
11. Protein synthesis is not inhibited by common antibiotics like chloramphenicol	11. Protein synthesis is inhibited by antibiotics like chloramphenicol.

CYTOSKELETAL STRUCTURES

They are extremely minute, fibrous and tubular structures which form the structural frame-work inside the cell. Cytoskeletal structures occur only in eucaryotic cells. They were discovered with the help of fluorescence microscopy. Cytoskeletal structures maintain shape of the cell and its extensions, regulate oreintation and distribution of cell organelles, intra cellular transport and movement of cells. They are of three types :– microfilaments, intermediate filaments and microtubules.

(i) **Microfilaments** (Paleviz *et al*, 1974). They are ultramicroscopic long, narrow cylindrical rods or protein filaments which occur in eukaryotic plant and animal cells. Microfilaments are made up of **actin** (also present in muscle myofibrils) constituting 10–15% of total cell protein. They are 6–8 nm in thickness and show periodic beaded appearance due to close helical arrangement of otherwise globular actin molecules (Fig. 8.43). Microfilaments often associate to form hexagonal **bundles.** They may also occur in parallel bundles or loose network. Microfilaments generally lie at sol-gel interphase as well as below plasma membrane. Microfilaments are also connected with spindle fibres, endoplasmic reticulum, chloroplast, etc. In some primitive organisms spindle apparatus seems to be made of microfilaments. During mitosis of animal cells, they have been found associated with cleavage furrows. Stabilisation of membrane proteins has recently been found to be related to their association with microfilaments.

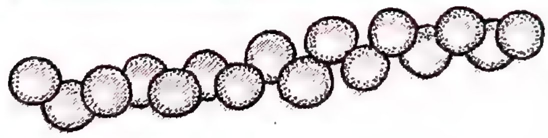


Fig. 8.43. Helical arrangement of actin molecules in a microfilament.

Microfilments are conctractile. Association with myosin protein seems to be essential for contraction of microfilaments. Myofibrils of muscle fibres also contain microfilaments. Microfilaments form the contractile machinery of the cell which aids in motility, like formation and retraction of pseudopodia and plasma membrane undulations, formation of microvilli, endocytosis, cytoplasmic streaming and movement of other cell organelles.

Microvilli are thread-like protoplasmic projections which are formed on the free surface of absorptive cells like those of intestine. Each microvillus is covered by an extension of plasmalemma. Its core contains a number of microfilaments. The microfilaments are attached to the plasmalemma extension.

Functions

1. *Cytoplasmic Streaming*. Cyclosis is caused by the activity of microfilaments.

2. *Membrane Proteins*. They help in stabilisation of membrane proteins.

3. *Support*. They are components of cytoskeleton of cell that is required to support otherwise fluid cytoplasmic matrix.

4. *Change in Form*. Microfilaments play an important part in change of cell form during development and differentiation.

5. *Myofibrils*. Myofibrils are contractile elements of muscles. They have microfilaments.

6. *Microvilli*. Microvilli are maintained through the support provided by microfilaments.

7. *Movement of Microvilli*. Microvilli show microfilament mediated movements. This aids in quicker absorption of materials.

8. *Membrane Undulations*. Fibroblasts are able to move due to plasma membrane undulations caused by microfilaments.

9. *Pseudopodia*. Microfilaments help in the formation and retraction of pseudopodia.

10. *Endocytosis* and *Exocytosis*. Microfilaments are responsible for changes in plasma membrane during endocytosis and exocytosis.

11. *Spindle Apparatus*. The spindle apparatus of few organisms is composed of microfilaments.

12. *Cleavage*. Microfilaments are associated with cleavage furrow at the time of cytokinesis.

13. *Movement of Cell Components*. Pigment granules, chloroplasts and other cell organelles are able to change their position inside the cytosol by means of microfilaments.

(ii) **Intermediate Filaments** (Fig. 8.44). They are nearly solid unbranched filaments of about 10nm thickness which are formed by a variety of proteins and often form a network. Intermediate filaments are of four types: (a) **Keratin Filaments.** They form tonofibrils of desmosomes and keratin of skin. (b) **Neurofilaments.** Filaments form a lattice with bundles of microtubules in axons and dendrons of nerve cells. (c) **Glial Filaments.** They are intermediate filaments found in astrocytes. (d) **Heterogeneous Filaments.** They are intermediate filaments found in muscles (Z-lines, M-lines), as basket around nucleus and connected to centriole, etc. Heterogeneous filaments are of three types— synemin filaments, vimentin filaments and desmin filaments. Intermediate filaments do not occur in unicellular eukaryotes. They evolved in multicellular eukaryotes. The filaments are cross linked with one another as well as various cellular structures including plasmalemma by means of IF associated proteins, *e.g.*, plakins, plectins.

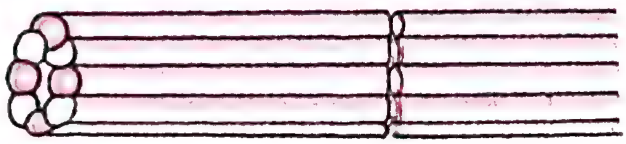


Fig. 8.44. Structure of intermediate filament.

Functions

1. **Nuclear Matrix.** It is mainly formed of intermediate filaments.

2. **Support to Membranes.** IF provide support to all biomembranes including plasmalemma and nuclear membranes.

3. **Cytoplasm.** IFs constitute scaffold or supporting array for cytoplasm.

4. **Muscles.** A lattice of desmin filaments not only surrounds each Z-disc but is also connected to sarcolemma. This provides support to contractile units or sarcomeres.

5. **Desmosomes.** Desmosomes are supported by intermediate filaments called **tonofibrils.**

6. **Epithelial Tissues.** IFs maintain the integrity of epithelial tissues.

7. **Keratin.** Keratin deposited in the skin cells provides protection against abrasions.

8. **Nervous Tissue.** Intermediate filaments provide mechanical strength to axons and dendrons of nerve cells (as neurofilaments) and astrocytes (as glial filaments).

(iii) **Microtubules** (De Robertis and Franchi, 1953). Microtubules are unbranched hollow submicroscopic tubules of protein tubulin which develop on specific nucleating regions and can undergo quick growth or dissolution at their ends by assembly or disassembly of monomers. Colchicine prevents assembly of microtubules. It, therefore, prevents spindle formation during cell division. With the exception of Slime Moulds and Amoebae, microtubules occur widely in eukaryotic cells. They are present in the cytoplasm as well as in specialized structures like centrioles, basal bodies, cilia or flagella, sensory hair, equatorial ring of thrombocytes, spindle apparatus, chromosome fibres, nerve processes, sperm tails, axostyle of parasitic flagellates, fibre system of *Stentor*, cyto-pharyngeal basket of *Nassula*, etc. Microtubules are of indefinite length. Their diameter is 25 nm with a core of 15 nm and wall of 5 nm thickness. The wall is formed of 13 laterally associated and helically arranged longitudinal strands called protofilaments. These strands are made of alternate spirals (Fig. 8.45) of two related proteins called α– and **β-tubulins.** The surface of a microtubule may also possess **arms**, lateral projections of 100–400 Å length and 20–50 Å thickness. They may help in forming cross-bridges among themselves and various types of cellular structures like plasmalemma, endoplasmic reticulum, nuclear envelope and other organelles. The arms seem to be involved in movement of cytosol in the area of microtubules.

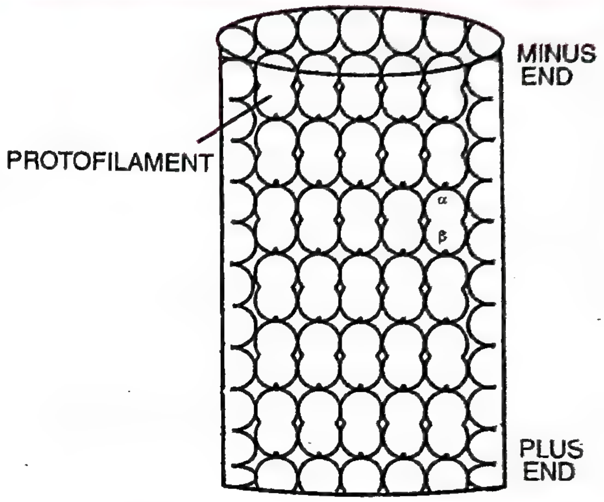


Fig. 8.45. Arrangement of tubulin molecules in a microtubule.

Functions

1. **Structural Components.** Microtubules are constituents of spindle fibres, chromosome fibres, centrioles, basal bodies, flagella and cilia.

2. **Cytoskeleton.** Microtubules function as cytoskeleton. They provide rigidity and shape to some cell parts like pseudopodia of some protistans and axons of nerve cells.

3. **Intracellular Transport.** They are believed to function either as microcirculatory system or directing movement of vesicles to a particular part with the help of their arms.

4. **Orientation of Microfibrils.** In plant cells the microtubules control orientation of cellulose microfibrils of the wall.

5. **Shape.** Distribution of microtubules control the shape of wall-less cells and nuclei.

6. **Nuclear Movements.** They help in the movement of nuclei during division.

7. **Movement of Chromosomes.** As chromosome or tractile fibrils, the microtubules take part in the anaphasic movement of chromosomes.

8. **Cell Plate.** Place of future cell plate formation has been found to be determined by a microtubular band.

9. **Pushing of Food.** In protistans, microtubules help in driving the food in the gullet.
10. **Cell Differentiation.** They are believed to play a vital role during differentiation.
11. **Cell Polarity.** Distribution of microtubules determines cell polarity.
12. **Movements of Cilia and Flagella.** Being capable of sliding past one another, microtubules help in the movement of flagella and cilia.
13. **Cell Movements.** Alongwith microfilaments they take part in cell movements.

Differences between Microfilaments and Microtubules

Microfilaments	*Microtubules*
1. They are contractile.	1. They are non-contractile though change in length can occur through assembly and disassembly of constituent proteins.
2. They do not possess longitudinal subunits.	2. A microtubule contains 13 protofilaments.
3. Microfilaments are solid structures.	3. They are hollow tubules.
4. Microfilaments are made up of actin protein.	4. Microtubules are formed of α and β-tubulin.
5. The diameter of a microfilament is 6 nm.	5. The diameter of a microtubule is 25 nm.
6. They occur below cell membrane and at the interphase of plasmagel-plasmasol.	6. Microtubules occur in centrioles, basal bodies, cilia/flagella, astral rays, spindle fibre.
7. Microfilaments are believed to cause cytoplasmic streaming.	7. Microtubules cause microcirculation by directing vesicles to particular direction.
8. They take part in endoytosis.	8. Microtubules have no role in endocytosis but direct endosomes in particular direction.

FLAGELLA AND CILIA

They are fine hair like movable protoplasmic processes of the cells which are capable of producing a current in the fluid medium for locomotion and passage of substances. Flagella are longer (100–200 μm) but fewer. Only 1–4 flagella occur per cell, *e.g.*, many protists, motile algae, spermatozoa of animals, bryophytes and pteridophytes, choanocytes of sponges, gastrodermal cells of coelenterates, zoospores and gametes of thallophytes. Cilia are smaller (5–20 μm) but are numerous. They occur in group ciliata of protista, flame cells of worms, larval bodies of many invertebrates, epithelium of respiratory tract, renal tubules, oviducal funnel, etc. Cilia present on the tracheal and bronchial epithelial cells are specialised to send back dust particles into the pharynx so that the lungs remain unharmed. However, cigarette smoking reduces/stops ciliary activity so that air borne dust particles pass into the lungs of smokers causing irrepairable harm.

Both cilia and flagella are structurally similar and possess similar parts— basal body, rootlets, basal plate and shaft (Fig. 8.46).

(i) *Basal Body or Kinetosome*. It is also called **basal granule** or **blepharoplast.** Basal body occurs embedded in the outer part of the cytoplasm below the plasma membrane. It is like a microcylinder which has a structure similar to a centriole with nine triplet fibrils present on the periphery without a central fibril, though a hub of protein is present here. Only subfibre A is complete (having 13 protofilaments) while subfibres B and C are incomplete as they share some of their protofilaments.

(ii) *Rootlets*. They are striated fibrillar outgrowths which develop from the outer lower part of the basal body and are meant for providing support to the basal body. The rootlets are made of bundles of microfilaments.

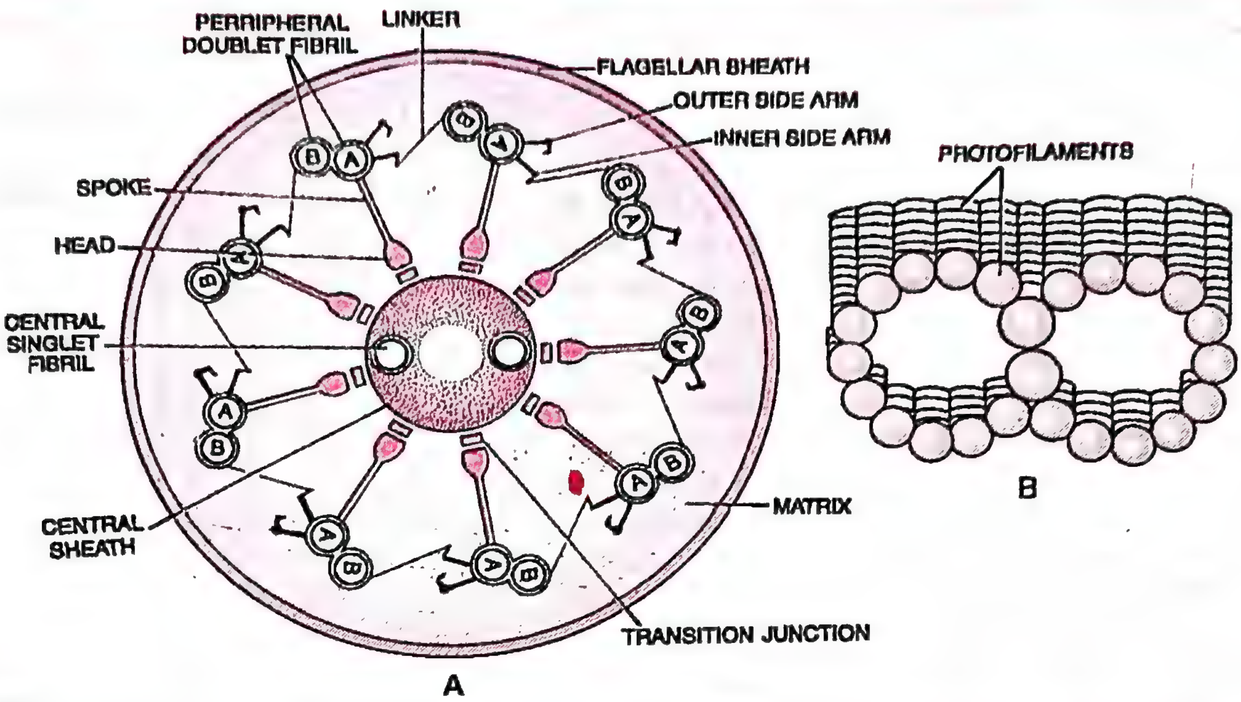


Fig. 8.46. A, ultrastructure of flagellum in cross-section. B, doublet fibril without arms.

(iii) *Basal Plate*. It is an area of high density which lies above the basal body at the level of plasma membrane. In the region of basal plate, one sub-fibre of each peripheral fibril disappears. The central fibrils develop in this area.

(iv) *Shaft*. It is the hair-like projecting part of flagellum or cilium. The length is 5–20 μm in case of cilium and 100–200 μm in case of flagellum. The shaft is covered on the outside by a sheath which is the extension of plasma membrane. In **whiplash flagellum**, the sheath is smooth. In **tinsel flagellum**, the sheath contains a number of thick hairy outgrowths called **flimmers**. Internally, it contains a semifluid matrix having an **axoneme** of 9 peripheral doublet fibrils and 2 central singlet fibrils (Fig. 8.46). This arrangement is called 9 + 2 or 11-stranded. However 9 + 1 (*e.g.,* flatworm) and 9 + 0 (*e.g.,* eel, Asian Horseshoe Crab) arrangements have also been observed. The two central singlet fibres are covered by a proteinaceous central sheath. They are connected by a double bridge. Each peripheral fibril consists of two microtubules or sub-fibres B and A. The sub-fibre A is slightly narrower. It bears two bent arms, the outer one having a hook. They are about 15 nm long and made up of protein **dynein** with ATP-ase activity. Such activity is also present in central fibrils. Movement of flagella or cilia occurs due to sliding motion in which dynein arm establishes temporary connection with subtubule B of adjacent doublet fibre. The peripheral doublet fibrils as well as central singlet fibrils are made up of tubulin. Each sub-fibre or central singlet fibril contains thirteen protofilaments. The peripheral doublet fibrils are interconnected by A-B linkers of protein **nexin** between B-subfibre of one and inner side arm of A-subfibre of adjacent fibril. Each of their A sub-fibres sends a radial proteinaceous column to the centre. It is called **spoke**. The spokes are broader internally to form heads or knobs. Head is connected to central proteinaceous sheath through transition junction.

The cilia and flagella move by sliding of the doublet fibrils against one another. Energy is provided by ATP. Flagella perform independent undulatory movements while cilia show rowing type of sweeping motion either simultaneously (isochronic or synchronous) or one

after the other (metachronic). In a flagellum, several symmetrical undulatory waves pass from base to the tip. This pushes the cell along. Undulations passing from tip to base pull the cell through water. In tinsel flagellum having a number of flimmers, the undulatory wave moving down from base to tip also pulls the cell along instead of pushing it. There is always a **power stroke** and a **recovery** or **return stroke** (Fig. 8.48). The power stroke is able to move the fluid with a jerk in the direction of the stroke. The cell moves in the opposite direction, if it is motile. The recovery or return stroke is slow and without much force. Therefore, it does not cause much disturbance in the fluid medium. Rate of ciliary and flagellar movements is 10–40 strokes per second. Flagellate *Monas stigmatica* swims at the rate of 260 μm or 40 cell length/sec. It has the maximum speed per body length. *Paramoecium caudatum* has a speed of 1500 μm or 12 cell lengths/sec.

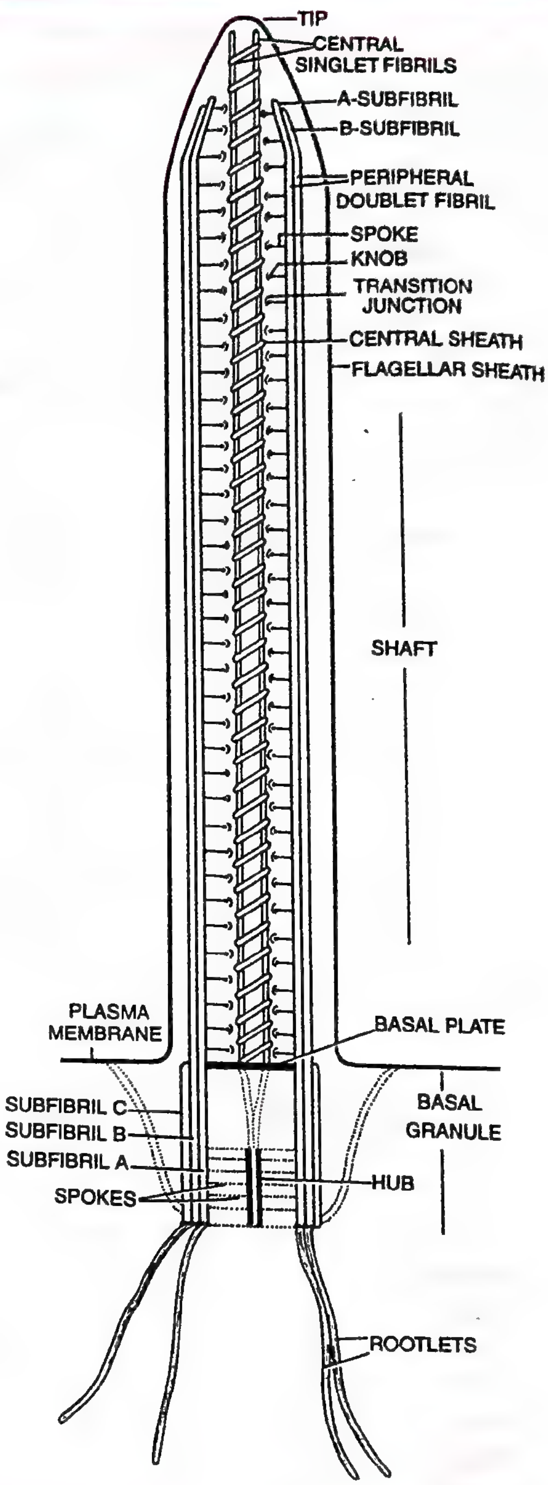


Fig. 8.47. L.S. of a flagellum

Functions of Cilia and Flagella

1. They help in locomotion in flagellate and ciliated organisms.
2. They create current for obtaining food from aquatic medium.
3. In some protists and animals, the organelles take part in capturing food.
4. The canal system of porifers operates with the help of flagella present in their collar cells or choanocytes.
5. In coelenterates, they circulate food in the gastrovascular cavity. In tunicates and lancelets, the cilia help in movement of food and its egestion.
6. In aquatic organisms cilia create currents in water for renewal of oxygen supply and quick diffusion of carbon dioxide.
7. In land animals the cilia of the respiratory tract help in eliminating dust particles in the incoming air.
8. Internal transport of several organs is performed by cilia, *e.g.*, passage of eggs in oviduct, passage of excretory substances in the kidneys, etc.
9. Being protoplasmic structures they can function as sensory organs.
10. Their tips secrete sticky substance to help in conjugation and fusion of gametes.
11. In certain protistans, cilia fuse to form undulating membrane.
12. Cilia and flagella show sensitivity to changes in light, temperature and contact.
13. Ciliated larvae take part in dispersal of the species.

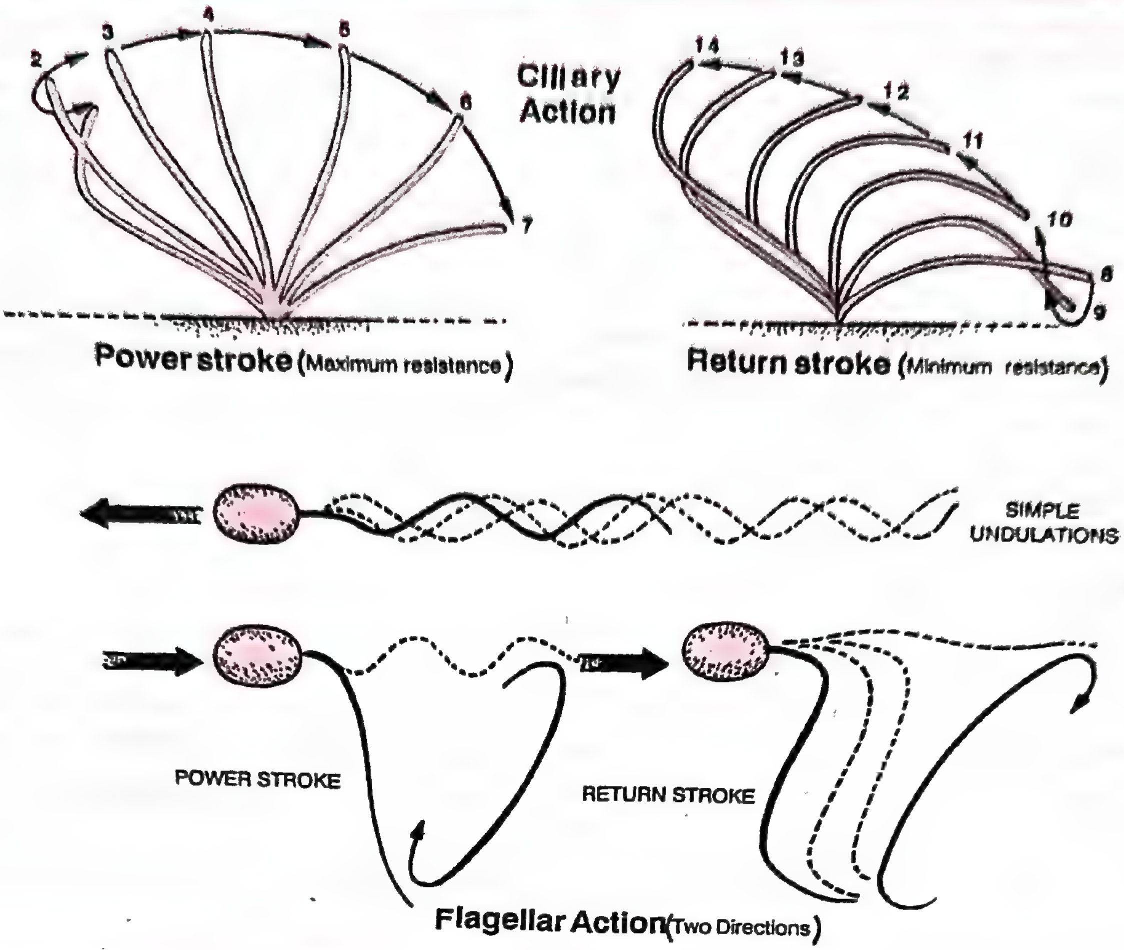


Fig. 8.48. The mode of movement in cilia and flagella.

Differences between Cilia and Flagella

Cilia	*Flagella*
1. The number of cilia per cell is usually very large (300—14000).	1. The number of flagella per cell is usually 1—4.
2. They are smaller (5—20 μm in length).	2. They are longer (100–200 μm in length).
3. Cilia usually occur throughout or major part of the surface of a cell.	3. Flagella are commonly found at one end of the cell.
4. They beat in a co-ordinated rhythm either simultaneously (isochronic or synchronous rhythm) or one after the other (metachronic rhythm).	4. The flagella beat independently.
5. Cilia produce a sweeping or pendular stroke.	5. The flagella produce undulatory motion.
6. Cilia help in locomotion, aeration, feeding circulation, etc.	6. Flagella help in locomotion.
7. Cilia may fuse to form undulating membrane.	7. Fusion of flagella is unknown.
8. Surface is smooth.	8. Surface may be smooth or possess flimmers.

CENTRIOLES

Centrioles are minute-submicroscopic microtubular subcylinders with a configuration of nine triplet fibrils and ability to form their own duplicates, astral poles and basal bodies,

without having DNA and a membranous covering. They are approximately 0.3–0.5 μm in length and 0.15μm in diameter. They are visible under light microscope, but the details of centriole structure were revealed only under electron microscope. Usually two centrioles are found associated together but at right angles to each other (Fig. 8.49). The pair of centrioles is often called **diplosome.** Diplosome lies in a common specialized part of cytoplasm called **centrosphere** or **kinoplasm** (= cytocentrum). Centrosphere is devoid of any other cell organelle. It, however, contains a fine fibrous material. The complex, formed of centrioles and centrosphere, is called **centrosome** (Boveri, 1888) or central apparatus.

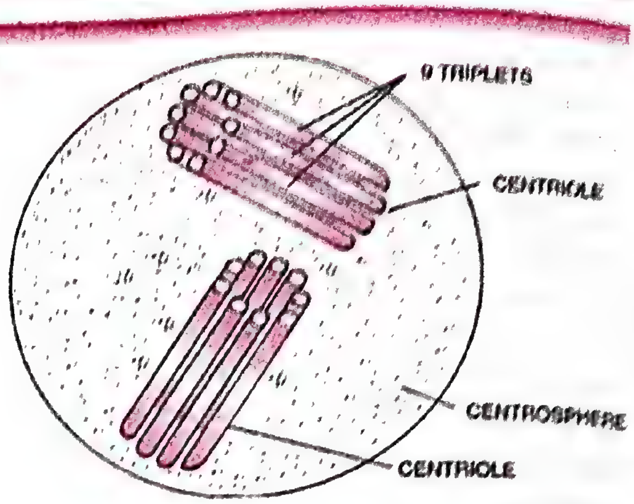


Fig. 8.49. Centrosome with pair of centroles (Diplosome).

Centrioles are found in almost all eukaryotic animal cells, protozoan protists (except some forms like *Amoeba*), some fungi and the cells of all those eukaryotic plants where flagellate structures are present in the life cycle (many green algae, bryophytes, pteridophytes and cycads). They are absent in angiosperms, higher gymnosperms, some algae and fungi.

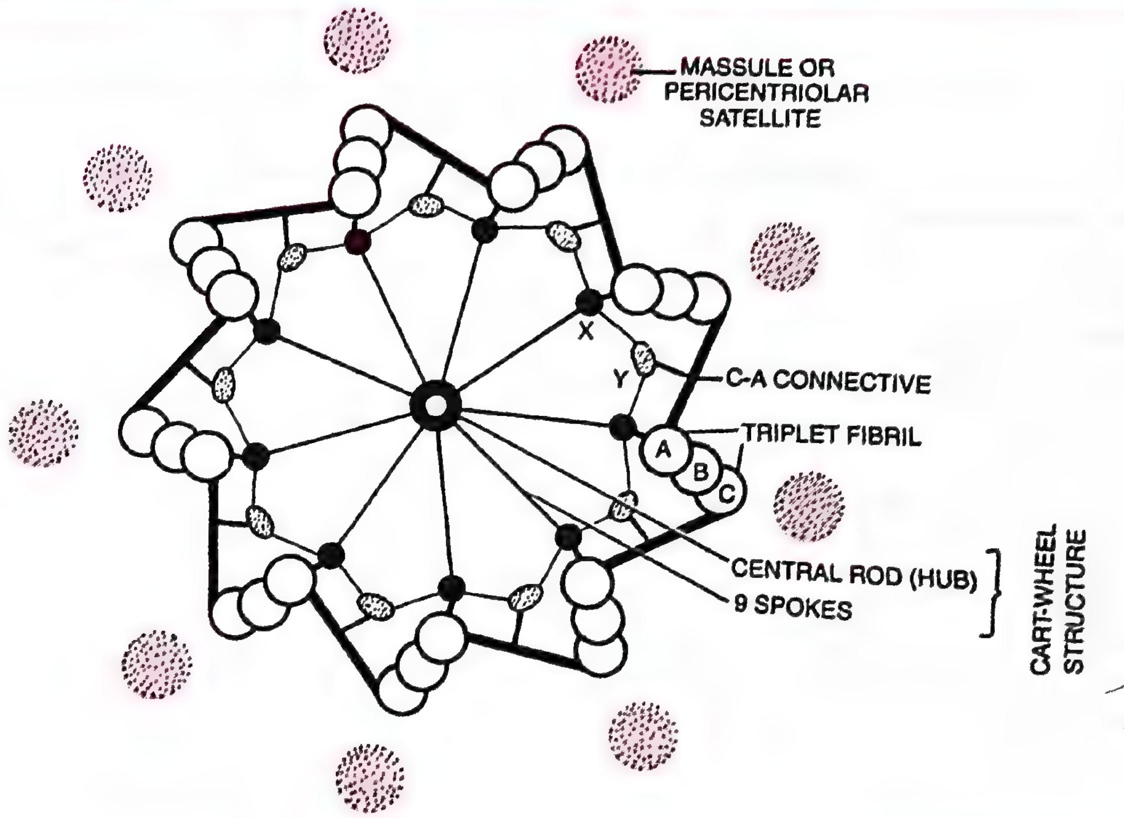


Fig. 8.50. Ultrastructure of centriole as seen in T.S.

Centrioles are capable of replication. Centriole replication is coordinated in animal cells with cell division. It occurs in S or G_2-phase. Prior to nuclear division, the two centrosomes separate and move to the opposite ends where spindle poles are to be established subsequently. Centriole replication also occurs at the time of formation of basal bodies of cilia and flagella.

A centriole possesses a whorl of nine peripheral fibrils. Fibrils are absent in the centre. The arrangement is, therefore, called 9 + 0. Fibrils run parallel to one another but at an angle of 40°. Each fibril is made up of three subfibres. Therefore, it is called **triplet** fibril. The three subfibres are in reality microtubules joined together by their margins and, therefore, sharing the common walls made of 2–3 protofilaments. Each subfibre has a diameter of 25 nm. From outside to inside the three sub-fibres of a triplet fibril are named as C, B and A. Subfibre A is complete with 13 protofilaments while B and C subfibres are incomplete due to sharing of some microfilaments.

The adjacent triplet fibrils are connected by C—A proteinaceous **linkers**. The centre of centriole possesses a rod-shaped proteinaceous mass known as **hub**. The hub has a diameter of 2.5 nm. From the hub, develops 9 proteinaceous strands towards the peripheral triplet fibrils. They are called spokes. Each spoke has a thickening called X before uniting with A sub-fibre. Another thickening known as Y is present nearby. It is attached both to X thickening as well as C—A linkers by connectives. Due to the presence of radial spokes and peripheral fibrils, the centriole gives a cart wheel appearance in T.S (Fig. 8.50).

On the outside of centriole are present dense, amorphous, protoplasmic plaques in one or more series. They are called **massules** or pericentriolar satellites. Their position is changeable with different states of the cell. Massules act as microtubule organising centre or **MTOC.** They are formed of gamma tubulins and function as nucleating centres for the growth of microtubules during aster formation and production of more centrioles (during G_2 phase).

Functions

1. Though centrioles have not been found to contain DNA, yet they are capable of forming new centrioles with the help of massules which function as nucleating centres.
2. Centrioles help in cell division by forming microtubule-organising centres (MTOCs).
3. Out of the two centrioles in a spermatozoan, the distal one forms axial filament or tail.
4. Centrioles can be transformed into basal bodies.
5. Basal bodies formed from centrioles give rise to cilia and flagella.

Resemblances among Centrioles, Cilium and Flagellum

Centriole, cilium and flagellum resemble one another in their broad structure and function. (i) All of them are made up of microtubules. (ii) The three possess nine peripheral fibrils of microtubules. Fibril organisation is 9 + 0 in centrioles and 9 + 2 in case of cilia and flagella. (iii) Basal granule present at the base of a cilium or flagellum is derived from a centriole and resembles the same in structure. (iv) All the three are capable of movements. Centriole does so to a limited extent inside the cytoplasm. A cilium or flagellum produces a current in an external liquid medium for locomotion, feeding, aeration and circulation. (v) Centrioles are parent organelles which produce basal bodies, cilia and flagella. They have nucleating centres or massules for the growth of microtubules.

Cell Inclusions

Cell inclusions are non-living substances present in the cells. They are also called ergastic bodies. They may be present in soluble or insoluble state and can be organic or inorganic in nature. The cell inclusions belong to three categories— reserve food, excretory or secretory products and mineral matter.

IV. NUCLEUS

Nucleus (L. *nucleus*– kernel) *is a specialized double membrane bound protoplasmic body which contains all the genetic information for controlling cellular metabolism and transmis-*

sion to the posterity. A nucleus in the non-dividing or metabolic phase is called **interphase nucleus.** Like other cellular structures, living unstained nucleus does not show much internal differentiation. For detailed study of nucleus, the cells must be properly killed, fixed and stained.

Nucleus is the largest cell organelle. Though first observed by Leeuwenhoek in red blood corpuscles of fish, nucleus was first studied in orchid root cells by Robert Brown in 1831. A nucleus is present in all living eukaryotic cells with the exception of mature sieve cells of vascular plants and red blood corpuscles of mammals. Even here a nucleus is present during the early stages of their development. Presence of hereditary information in the nucleus was proved by the work of Joachim Hammerling (1953) on single celled alga *Acetabularia* (Fig. 8.51).

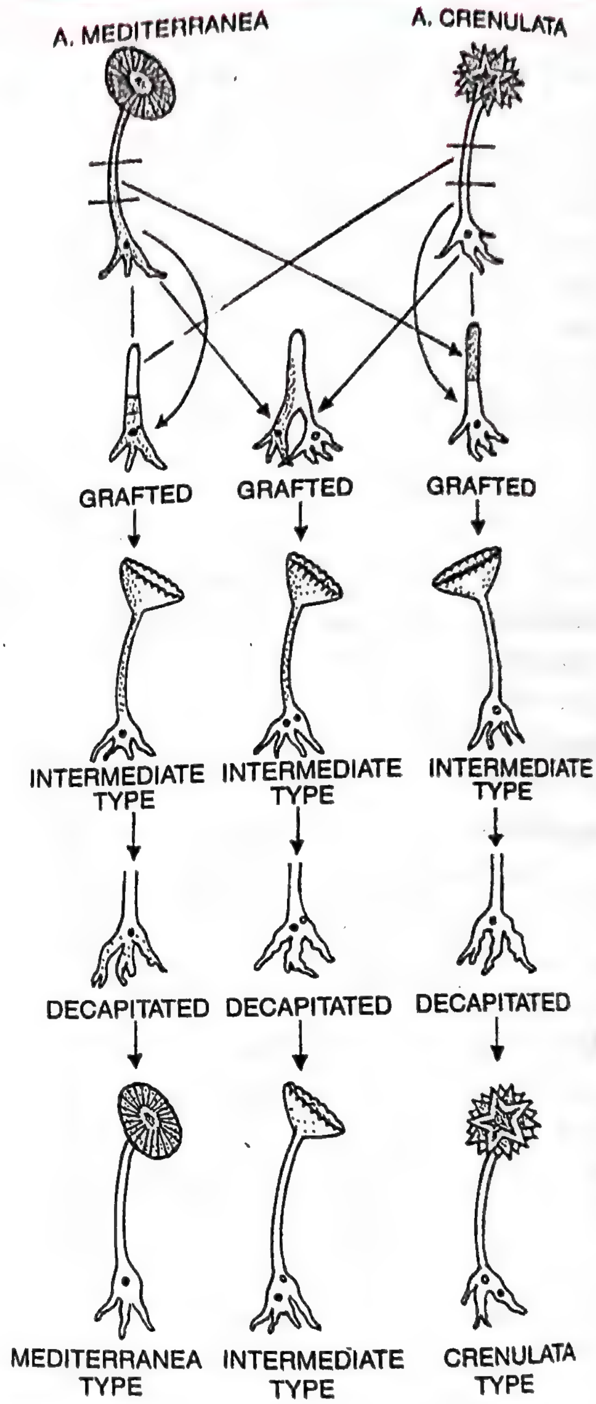


Fig. 8.51. Hammerling's Grafting experiment on *Acetabularia* to show the influence of nucleus on the morphology and development of plant.

Number. Commonly cells are **uninucleate**, that is, they possess a single nucleus. The protistan *Paramecium caudatum* has two nuclei (**binucleate**), macronucleus for controlling metabolic activities of the organism and micronucleus possessing hereditary information. **Multinucleate** or polynucleate condition is found in some cells of bone marrow, striated muscles, latex vessels, several fungi and algae. Multinucleate animal or protistan cells are called **syncytial cells** (*e.g.*, epidermis of *Ascaris*) while in plants and fungi they are called **coenocytic cells** (*e.g., Rhizopus, Vaucheria*). Acellular slime moulds have a multinucleate protoplasmic body called **plasmodium.**

Position. Nucleus is usually found in the region of maximum metabolic activity in the cytoplasm. Commonly it is situated in the geometric centre of the cell. In plant cells it is pushed to peripheral position on one side due to the development of a large central vacuole. Nucleus is peripheral in fat-storing cells or adipocytes, and basal in glandular cells. It is suspended in central vacuole by cytoplasmic strands in *Spirogyra*.

Shape. The nuclei are generally rounded in outline. They appear oval or elliptical in plant cells having large central vacuoles. Disc-shaped nuclei occur in the cells of squamous epithelium, lobed in white blood corpuscles and irregularly branched in silk spinning cells of insects.

Biochemical Analysis. DNA– 9–12%. RNA– 5%. Lipids– 3%. Basic Proteins– 15%. Acid proteins, neutral proteins and enzymes– 65%. Traces of minerals like Calcium, Magnesium, Potassium and Sodium (Phosphorus is a constituent of **DNA, RNA** and acid proteins).

Ultrastructure. A typical interphase nucleus is 5–25 μm in diameter. It is differentiated into five parts— nuclear envelope, nucleoplasm, nuclear matrix, chromatin and nucleolus (Fig. 8.53).

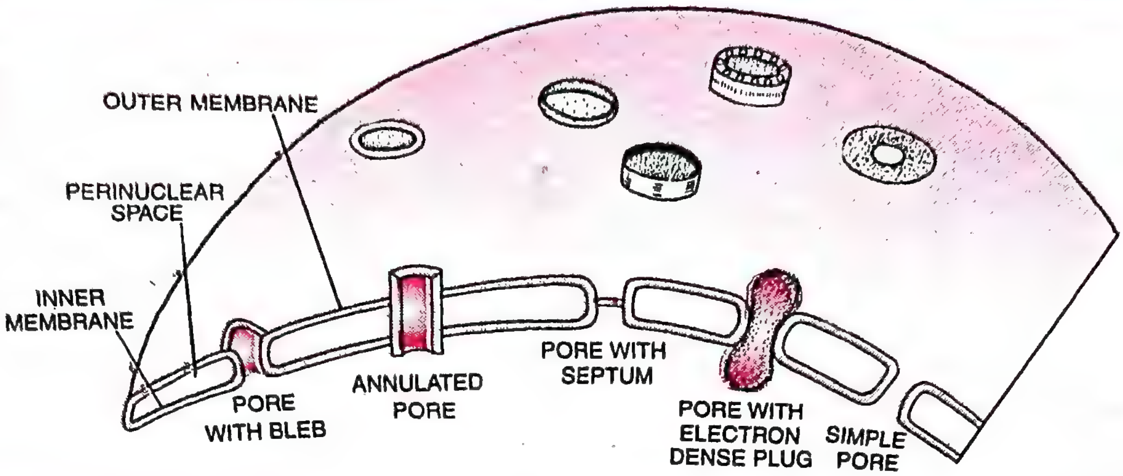


Fig. 8.52. Nuclear pores in surface and sectional views of nuclear envelope.

1. **Nuclear Envelope** (= Karyotheca). It bounds the nucleus on the outside. The nuclear envelope separates the nucleus from the cytoplasm. It is made up of two lipoprotein and trilaminar membranes, each of which is 60–90Å thick. The inner membrane is smooth. The outer membrane may be smooth or its cytoplasmic surface may bear ribosomes like the rough endoplasmic reticulum. The two membranes of the nuclear envelope are separated by an electron transparent **perinuclear space**. The space is 100–500 Å in width. The outer membrane is often connected to endoplasmic reticulum.

Nuclear envelope contains a large number of pores or perforations (Fig. 8.52). In some cases 10% of the envelope is occupied by pores. The two membranes of the envelope become continuous in the region of pores. Pores are formed of proteins calld **nucleoporins.** Nuclear pores have complex structure. They may have diaphragm, septum, plug of electron dense material or nucleoplasmin, blebs or annuli. Annuli are circular structures around the pores. The pores and their annuli form a **pore complex** called **annulated pore**. An annulated nuclear pore may possess 9 cylinders, one central and eight peripheral. Instead, there may be a network of granules and filaments.The nuclear pores control the passage of substances to the inside or outside of the nucleus, *e.g.*, RNAs, ribosomes, proteins.

2. **Nucleoplasm** (Nuclear Sap, Karyolymph, Strasburger, 1882). It is a transparent, semifluid and colloidal substance which fills the nucleus. It contains nucleosides and a number of enzymes (*e.g.*, DNA polymerase, RNA polymerase, nucleoside phosphorylase) which are required for the synthesis and functioning of DNA, RNA, nucleoproteins, etc. Some of the proteins present in nucleoplasm are essential for spindle formation.

3. **Nuclear Matrix.** It is a network of fine fibrils of acid proteins that function as scaffold for chromatin. On the periphery, below the nuclear envelope, nuclear matrix forms a dense fibrous layer called **nuclear lamina** or **fibrous lamina**. In animal cells, fibrous lamina is made of three types of lamins A, B and C. In plant cells, it is formed of coiled coil domain of matrix proteins (Ciska and Espina 2013). Terminal ends of chromatin fibres or telomeres are embedded in nuclear or fibrous lamina. Nuclear matrix consists of two types of intermediate filaments, lamin A and lamin B. Nuclear matrix and nuclear lamina form (i) Scaffold for chromatin. (ii) Attachment sites to telomeric parts. (iii) Mechanical strength to nuclear envelope. (iv) Components of nuclear pore complex.

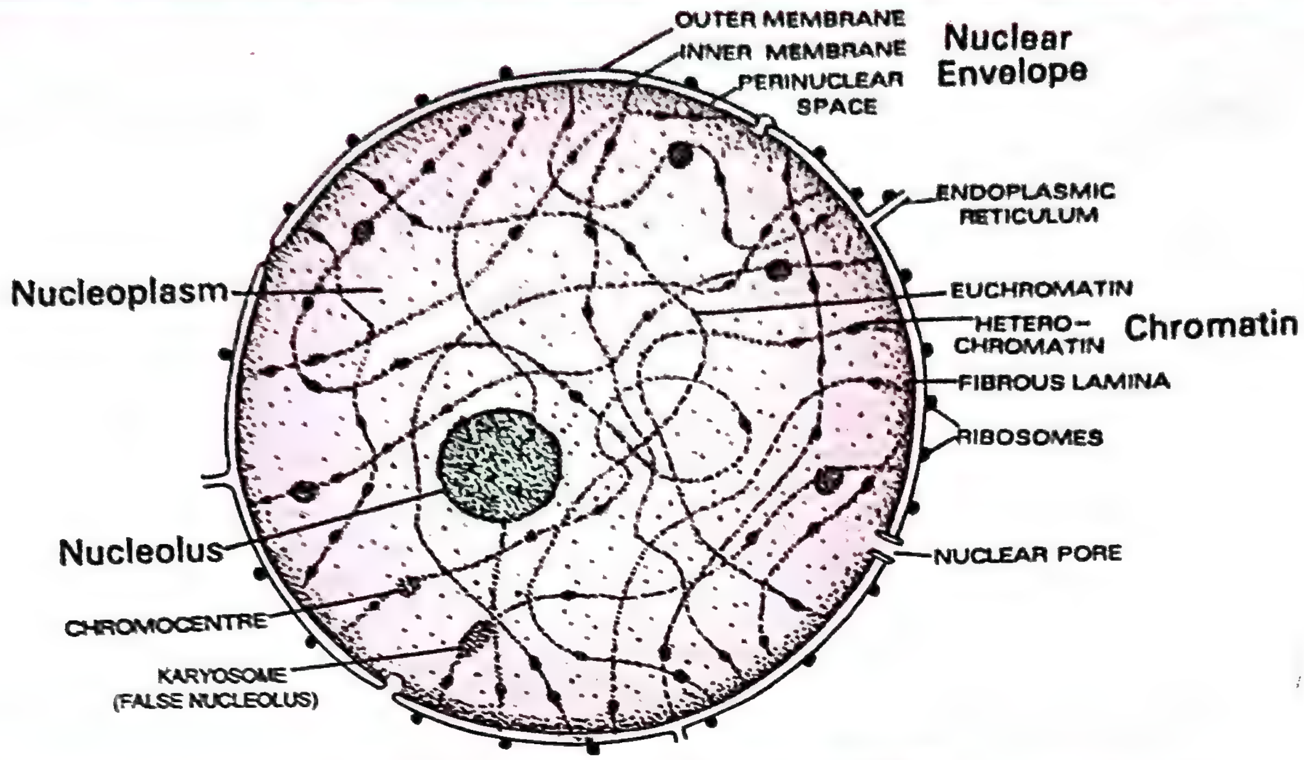


Fig. 8.53. Ultrastructure of interphase nucleus.

4. **Chromatin.** It is hereditary DNA-protein fibrillar complex which is named so because of its ability to get stained with certain basic dyes (Gk. *chroma*— colour; Flemming, 1879). Chromatin occurs in the form of fine overlapping and coiled fibres which appear to produce a network called **chromatin reticulum**. Chromatin fibres are distributed throughout the nucleoplasm. They are differentiated into two regions— **euchromatin** and **heterochromatin**, Heitz (1928). Euchromatin is narrow (10–30nm thick) lightly stained and diffused fibrous part which forms the bulk of chromatin. Heterochromatin is wider (100 nm thick), darkly stained and condensed granular part which is attached here and there on the euchromatin. Depending upon the size of granules formed by heterochromatin they are called **chromocentres, karyosomes** or **false nucleoli**.

Differences between Euchromatin and Heterochromatin

Euchromatin	*Heterochromatin*
1. It is narrower, 10-30 nm in diameter.	1. Heterochromatin is thicker, 100 nm in diameter.
2. Euchromatin is lightly stained.	2. It is darkly stained.
3. It is somewhat diffused.	3. Heterochromatin is condensed.
4. Euchromatin is fibrous.	4. Heterochromatin is granular.
5. It forms the bulk of chromatin.	5. It is present at certain places in the chromatin.
6. It contains active genes.	6. Heterochromatin does not possess active genes.
7. Euchromatin takes part in transcription.	7. Transcription is absent in heterochromatin.
8. Euchromatin is affected by a number of factors like *p*H, temperature and hormones.	8. Heterochromatin is not influenced by these factors.
9. Crossing over is quite common.	9. Hetertochromatin inhibits crossing over.
10. It replicates early.	10. It replicates late in the S-phase.
11. Nucleosome strand has minimum coiling.	11. Nucleosome strand has solenoid coiling.

The whole of chromatin is not functional. Generally only a portion of euchromatin which is associated with acid proteins takes part in transcription or formation of RNAs.

During prophase of nuclear division, the chromatin fibres condense to form a definite number of thread-like structures called chromosomes.

Differences between Chromatin and Chromosomes

Chromatin	*Chromosomes*
1. It is uncondensed part of nucleoprotein complex.	1. Chromosomes are condensed parts of the nucleoprotein complex.
2. Chromatin is observable in the interphase nucleus.	2. Chromosomes are observable during M-phase or nuclear division.
3. Chromatin is in the form of fine fibrils that run throughout the nucleus.	3. Chromosomes are in the form of short thick threads or rods.
4. Replication occurs in the chromatin phase.	4. It cannot occur in chromosome phase.
5. The replicas are not discernible.	5. Replicas are visible as chromatids.
6. It is active in controlling metabolism and other activities of the cell.	6. Chromosomes are mainly meant for distribution of genetic information to the daughter cells.

5. **Nucleolus** (plural– nucleoli). It was first discovered by Fontana in 1781, described by Wagner in 1840 and provided with its present name by Bowman in 1840. Nucleolus is a naked, round or sightly irregular structure which is attached to the chromatin at a specific region called **nucleolar organiser region** (NOR). Commonly 1–4 nucleoli are found in a nucleus. Upto 1600 nucleoli are reported in the oocytes of *Xenopus*.

A covering membrane is absent around nucleolus. Because of this the contents of nucleolus are in direct contact with the nucleoplasm. However, Calcium seems to help in maintaining its configuration. Nucleolus has four components— amorphous matrix, granular part, fibrillar portion and chromatin (Fig. 8.54).

(a) *Amorphous Matrix.* It is the homogeneous ground substance of the nucleolus. Matrix is formed of protein.

(b) *Granular Portion.* It consists of granules of the size of 150–200 Å which lie scattered in the amorphous matrix. The granules are formed of protein and RNA in the ratio of 2 : 1. They are believed to be precursors of ribosomes.

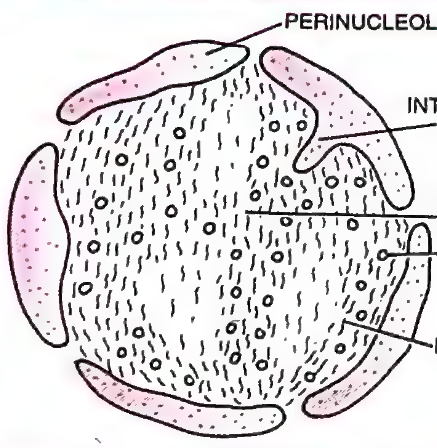


Fig. 8.54. Detailed structure of nucleolus.

(c) *Fibrillar Portion* (Nucleolonema). It is formed of a large number of small fibrils that are 50—80 Å long. The fibrils are made up of both protein and RNA and are believed to be precursors of granules.

(d) *Chromatin Portion.* It is that part of chromatin which is associated with nucleolus. Depending upon its position nucleolar chromatin is of two types— perinucleolar and intranucleolar. The perinucleolar chromatin lies around the periphery of the nucleolus. It gives rise to ingrowths or trabeculae which produce the intranucleolar chromatin.

(i) Nucleolus is the principal site for the development of ribosomal RNAs. (ii) It is the centre for the formation of riυosome components. (iii) Nucleolus stores nucleoproteins. The

same are synthesised in the cytoplasm (over the ribosomes) and transferred to nucleolus. (iv) It is essential for spindle formation during nuclear division.

Functions. Nucleus is an essential and integral part of the eucaryotic cell. It stores genetic information in its DNA molecules which can be passed on to daughter cells. It also controls cellular activities.

1. *Chromatin*. Nucleus contains hereditary material called chromatin. Chromatin is DNA-protein complex. It is made of a number of fine fibres that condense to form chromosomes. Number of chromosomes is fixed for a species. They bear genes.

2. *Genetic Information*. Chromatin part of nucleus possesses all the genetic information that is required for growth and development of the organism, its reproduction, metabolism and behaviour (Hammerling, 1953).

3. *Cellular Activities*. Nucleus controls cell metabolism and other activities through the formation of RNAs (mRNA, rRNA, tRNA) which control synthesis of particular type of enzymes.

4. *Ribosomes*. Ribosomes are formed in nucleolus part of the nucleus.

5. *Variations*. All variations are caused by changes in genetic material present in the nucleus.

6. *Cell Growth and Maintenance*. With the help of RNAs, nucleus directs the synthesis of some structural proteins and chemicals required for cell growth and maintenance.

7. *Cell Differentiation*. It directs cell differentiation by allowing certain particular sets of genes to operate.

8. *Cell Replication*. Replication of nucleus is essential for cell replication.

Differences between Cytoplasm and Nucleoplasm

Cytoplasm	*Nucleoplasm*
1. It is the general mass of protopasm which lies outside the nucleus.	1. It is the general mass of nucleus.
2. Cytoplasm is surrounded by a single membrane envelope called plasmalemma.	2. Nucleoplasm is covered on the outside by double membrane envelope called nuclear envelope.
3. The outer part of the cytoplasm is clear and gel-like and is called ectoplasm.	3. Sol-gel differentiation is not clear.
4. A dense fibrous lamina-like structure is absent.	4. Nucleoplasm contains a fibrous matrix. Its outer part is dense and forms fibrous lamina in contact with nuclear envelope.
5. Cytoplasm possesses a number of organelles and supporting structures.	5. The nucleoplasm contains three structures–chromatin, matrix and nucleolus.
6. It is under constant motion or cyclosis.	6. Cyclosis or streaming is absent.
7. The fluid part of cytoplasm contains a number of chemicals like minerals, nucleotides, amino acids, sugars, proteins and enzymes.	7. Nucleoplasm possesses small amount of minerals, sugar and amino acids. There are abundant nucleosides, nucleotides, proteins and enzymes.
8. It contains endomembranes.	8. Endomembranes are absent.
9. It is site of ribosome functioning.	9. It is site of ribosome formation.
10. Cytoplasm is the part of cell connected with various metabolic activities and functions.	10. Nucleoplasm is part of cell, that contains genetic material for controlling cytoplasmic structure and function.
11. It forms the bulk of cells.	11. It forms a small part of cell.

CHROMOSOMES

They are rod shaped or threadlike deeply stainable condensed chromatin fibres which are hereditary vehicles as they store and transmit coded hereditary information. Chromosomes appear only during karyokinesis. They are meant for equitable distribution of genetic material. The number is fixed and is the same in all the individuals of a species. There is a single set in gametophytic or haploid forms and two sets in sporophytic or diploid forms. Size and shape of individual chromosomes are quite distinct. The shape is more clearly visible in late prophase and metaphase (as well as anaphase) when primary constriction or centromere becomes distinct. During prophase and metaphase, the chromosomes are replicated. There are two chromosome halves or **chromatids**. The two chromatids are attached to each other by a narrow area called **centromere** or **primary constriction**. Anaphasic chromosomes do not have chromatids. The two parts of a chromosome or chromatid on either side of primary constriction are called **arms**. The two arms are equal in **isobrachial chromosomes** and unequal in **heterobrachial chromosomes**. The ratio between the two arms of a chromosome is called **centromeric ratio**. Based on the position of centromere, chromosomes are of four types (Fig. 8.55): (i) **Telocentric**. Centromere terminal in the area of telomere. (ii) **Acrocentric**. Centromere inner to telomere (= subterminal). (iii) **Submetacentric.** Centromere submedian (iv) **Metacentric.** Centromere median.

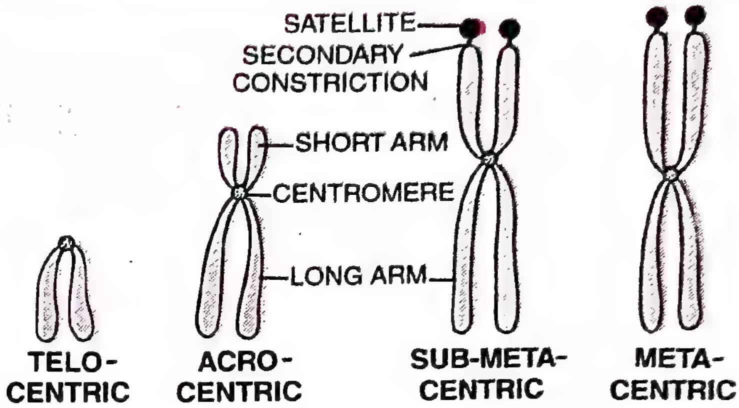


Fig. 8.55. Types of chromosomes on the basis of position of centromere.

Besides primary constriction or centromere, a chromosome may have one or more secondary constrictions. A secondary constriction present near the distal part of an arm may develop a small outgrowth or fragment called **satellite**. Satellite is connected to secondary constriction through a chromatin thread. A chromosome having satellite is called **sat chromosome**. Sat chromosomes are called **marker chromosomes**. Other secondary constrictions can also function as markers because they occupy a constant position.

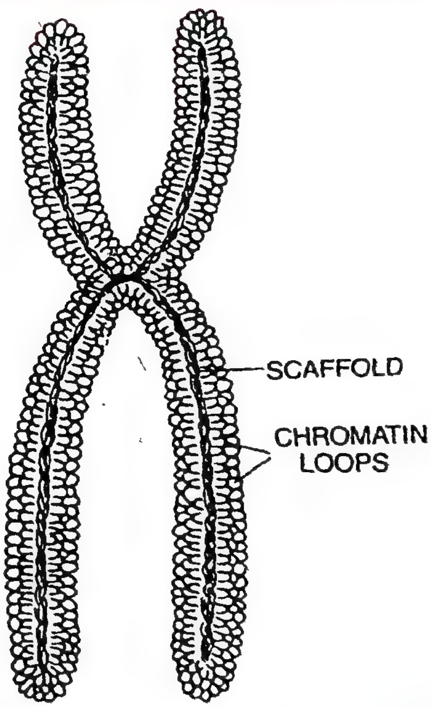


Fig. 8.56. Structure of chromosome.

Under light microscope, cytologists found that a chromosome contains a coiled filament called **chromonema**. Chromonema was thought to be gene bearing part. Some workers thought that a chromosome may have several chromonemata. Electron microscope has revealed that a chromosome is actually formed by direct condensation of loops of chromatin fibre attached to a scaffold. It is 30 nm in diameter and contains a single DNA duplex.

Giant Chromosomes

They are of two types, polytene and lampbrush.

Polytene Chromosomes (Gk. *polys*– many, *tainia*– threads; Kollar, 1882). Polytene chromosomes were first reported by E.G. Balbiani in 1881. They are quite common in salivary glands of insects and are, therefore, popularly called **salivary chromosomes.** Polytene chromosomes also occur in other organs of insects, antipodal cells (of embryo sac), endosperm cells and suspensor cells of embryo (Nagl, 1974; Malik and Singh, 1979). The chromosomes can reach a length of 2000 μm and contain 1000 (*Drosophila*) to 16000 (*Chironomus*) times DNA as compared to the ordinary somatic chromosomes. Polytene chromosomes are multistranded. They are in permanent prophase stage. The giant chromosomes are formed by **somatic pairing** between homologous chromosomes and repeated replication (endomitosis) of their chromonemata.

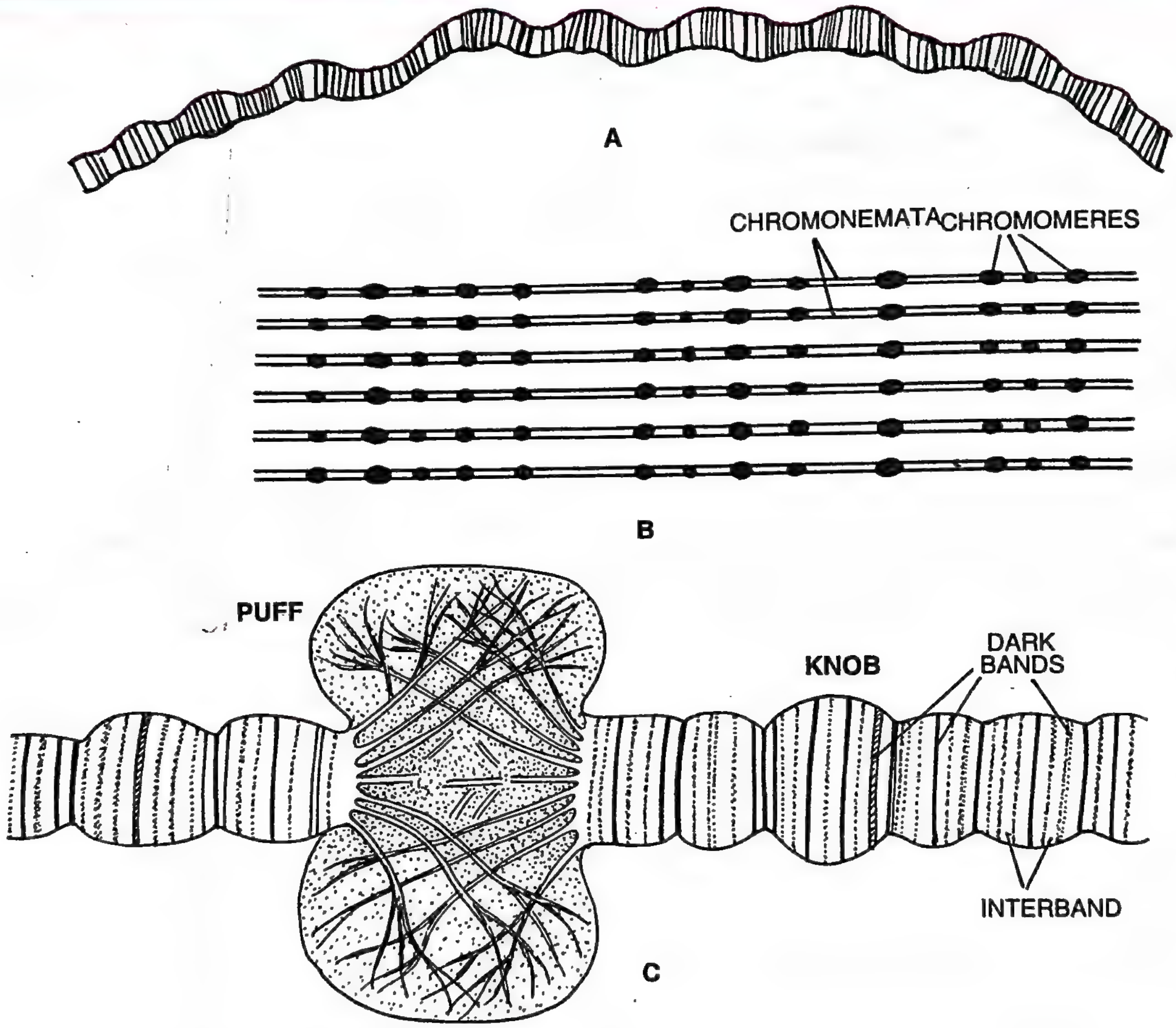


Fig. 8.57. Polytene chromosome. A, a typical polytene chromosome. B, schematic representation of formation of a polytene chromosome and its dark bands by coming together of a number of chromonemata and their chromomeres. C, an enlarged portion of polytene chromosome showing a puff.

All the polytene chromosomes may remain attached to one another at a common point called chromocentre. It represents pericentromeric heterochromatin which is slow to replicate. Polytene cells and their nuclei are large-sized. Polytene cells cannot divide further. They ultimately die. The adult organs develop from some small-sized diploid cells lying nearby.

Depending upon their reaction to basic dyes, the polytene chromosomes bear a number of dark **bands** of various sizes and intensity. They are separated by light areas called

interbands. The dark bands are presumed to be formed by the juxtaposition of chromomeres of the different chromonemata of a polytene chromosome (Fig. 8.57 B).

In certain developmental stages the polytene chromosomes bear conspicuous swellings called chromosome **puffs** (Fig. 8.57 C). The larger swellings are called **Balbiani rings.** In the region of a puff or Balbiani ring, the DNA strands uncoil, become active and produce number of copies of messenger or mRNA. The mRNAs may remain temporarily stored in the puff. Puffs are not permanent. At different physiological or developmental stages different bands uncoil to produce puffs. Puffs are withdrawn after the completion of the stage. By correlating puffs with different physiological or developmental processes scientists have been able to locate genes on the polytene chromosomes and prepare chromosome maps.

Differences between Polyteny and Polyploidy

Polyteny	*Polyploidy*
1. Homologous chromosomes undergo somatic pairing.	1. Pairing of homologous chromosomes does not occur in somatic cells.
2. The products of polyteny remain attached to one another.	2. Similar chromosomes remain separate from one another.
3. Polyteny produces hundreds of copies of the same chromosome.	3. Polyploidy does not increase in number of chromosomes beyond 6-10 times.
4. Polytene chromosomes are visible in the interphase nucleus.	4. Chromosomes are not visible in the interphase nucleus.
5. Polytene cells cannot multiply. They are destined to die.	5. Polyploid cells behave like normal cells.

Lampbrush Chromosomes (Fig. 8.58). The lampbrush chromosomes are highly elongated special kind of synapsed mid-prophase or **diplotene chromosome bivalents** which have already undergone crossing over. They were first seen by Flemming (1882) but were described by Ruckert (1892). Lampbrush chromosomes occur in diplotene stage of most animal oocytes, spermatocytes of many and even giant nucleus of unicellular alga *Acetabularia* (Spring *et al*, 1975). The lampbrush chromosomes are larger than even polytene chromosomes. Their total length in a urodele oocyte may be upto 5900 μm or three times the aggregate length of total polytene chromosomes.

Lampbrush chromosomes occur in pairs. The pair consists of homologous chromosomes which are joined at certain contact points called **chiasmata**. Each chromosome has a double main axis due to presence of two elongated chromatids. Both the chromatids bear rows of large number of chromomeres. Two adjacent chromomeres are separated by interchromomeric stretches. Many of the chromomeres give out **lateral** projections or **loops**. The lateral loops provide a test tube or lampbrush-like appearance to the chromosome pair. Length of a lateral loop may vary from 5–100 μm. Loops are uncoiled or expanded parts of a chromomere with one to several transcriptional units. Usually a lateral loop has a thin or uncoiling part and a thick or coiling part. Lateral loops take part in rapid transcription of mRNA meant for synthesis of yolk and other substances required for growth and development of meiocytes. RNA synthesis begins at the thinner end. It progresses towards the thicker end. The transcripts alongwith their binding proteins remain attached to the loop and give it a fine fibrillar appearance. Some mRNAs produced by lampbrush chromosomes may be stored as **informosomes** (mRNA + protein) for producing biochemicals during early development of embryo. After the full development of meiocytes, the lateral loops are withdrawn and the chromosomes shorten.

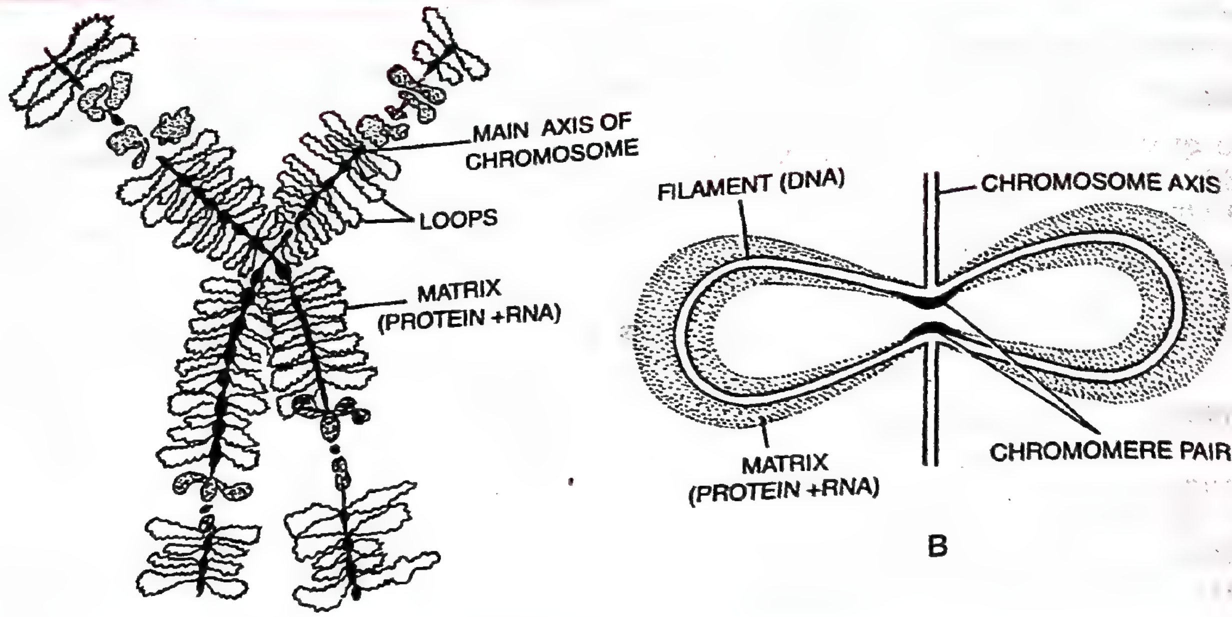


Fig. 8.58. Lampbrush chromosome . A, Enlarged view of a part of lampbrush chromosome. B, One loop of a lampbrush chromosome.

Chromosome Functions

1. Chromosomes contain genes. All the hereditary information is located in the genes.
2. Chromosomes control the synthesis of structural proteins and thus help in cell division and cell growth.
3. They control cellular differentiation.
4. By directing the synthesis of particular enzymes, chromosomes control cell metabolism.
5. Chromosomes can replicate themselves or produce their carbon copies for passage to daughter cells and next generation.
6. Sat chromosomes produce nucleoli for synthesis of ribosomes.
7. Their haploid or diploid number respectively bring about gametophytic and sporophytic characteristics to the individual.
8. Chromosomes form a link between the offspring and the parents.
9. Some chromosomes called sex chromosomes (*e.g.*, X and Y or X and 0) determine the sex of the individual.
10. Through the process of crossing over, chromosomes introduce variations.
11. Mutations are produced due to change in gene chemistry.

ADDITIONAL INFORMATION

- G.N. Rama Chandran (1922-2001) was an outstanding figure in the field of protein structure. He discovered triple helical structure of collagen protein with the help of his graphic technique called Ramachandran Plot.
- Karyotype is described in the form of an **idiogram**. The latter is a photograph or diagram of metaphasic chromosomes of an organism arranged in homologous pairs according to their length, thickness, position of centromere, length of arms, shape and other characteristics.

- **Smallest Human Cells.** Erythrocytes— 6 - 8 μm in diameter. Blood platelets are 2 - 3 μm in diameter but they are considered to be cell fragments instead of being cells themselves.
- **Plasmodium sporozoite.** 2μm in length.
- **Size of Human Gametes.** Human sperm is 60 μm in length while human egg is 100 μm in diameter.
- **Dual Existence.** Cells of multicellular organisms have dual existence, one for themselves and the other as components of the individual.
- **Membrane Channels.** They are of two main types, **aqueous channels** for the passage of water and **ion channels** for the passage of ions. Nehar and Sakmann were awarded Nobel Prize (1991) for discovery of single ion channels.
- **Membrane Fluidity.** It increases with the increase in number of lipids with unsaturated fatty acids and small chain fatty acids. While tails of the former possess kinks, the tails of the latter develop only weak bonds.
- **Microvilli.** They do not increase absorptive surface area. Microvilli are regions with high mechanical strength. Absorption occurs through pinocytosis in the depressions between adjacent microvilli.
- **Lewis** (1931). Discovered pinocytosis. Pinosomes are small and are not visible under optical microscope.
- **Metchnikoff** (1883). Discovered phagocytosis.
- **Adsorptive Pinocytosis.** It occurs in case of macromolecules like proteins. Membranes possess special receptor areas for them. As soon as the macromolecule attaches to the receptor site, the latter invaginates to form pinosome. Not much fluid is taken in. These pinosomes are directly passed to the region of use like Golgi complex. They are also called **receptosomes**.
- **Cell Organelles Without Membrane Covering.** Ribosome, Centrosome, Centriole, Nucleolus (inside nucleus), Cytoskeletal Structures.
- **Cell Organelles With Single Membrane Covering.** Endoplasmic Reticulum, Golgi Apparatus, Vacuole, Lysosome, Sphaerosome, Peroxisome, Glyoxysome, Thylakoid (Lamella, inside chloroplast).
- **Cell Organelles With Double Membrane Covering.** Plastids (Leucoplast, Chloroplast, Chromoplast), Mitochondrion.
- **Largest Organelle** mitochondrion in animal cell and chloroplast in photosynthetic plant cell.
- **Smallest Organelle.** Ribosome, Microfilament is the smallest structure.
- **GERL.** Golgi body, Endoplasmic Reticulum and Lysosome complex. **GER** is Golgi body and Endoplasmic Reticulum complex.
- **Medium for free Cell Organelles.** Cell organelles cannot be kept in water because they would burst like erythrocytes kept in water. Cell organelles can be maintained only in solution of specific concentration like 0.25% sucrose solution.
- **Ergastoplasm.** Endoplasmic reticulum of Garnier (1897).
- **Ergasome.** Polyribosome.
- **Ergastic Substances.** Cell inclusions.
- **Cellulose Microfibrils.** Each microfibril is formed of 20 elementary fibrils or micelles with each of the latter having about 100 cellulose molecules. Some 250 microfibrils may aggregate to produce a single macrofibril. A cotton fibre has 1500 macrofibrils (= fibrils).
- **Chloroplasts.** They are of two types, agranal (without grana) and granal (with grana). Agranal choroplasts occur in bundle sheath cells of C_4 plants, algae and **bryophytes.**
- **Transfer Cells.** They are plant cells specialised in transfer of solutes.
- **Apoptosis.** Genetically controlled cell death.
- **Overton** (1902). Plasma membrane is made of a thin layer of lipids.
- **Gorter and Grendell** (1926). Plasma membrane contains a double layer of lipid molecules.
- **Leeuwenhoek.** He was the first to observe many cellular structures including nucleus and chloroplasts, but is not credited with their discovery.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Which of the following is not correct ? (a) Robert Brown discovered the cell. (b) Schleiden and Schwann formulated the cell theory. (c) Virchow explained that the cells are formed from pre-existing cells. (d) A unicellular organism carries out its activities within a single cell.
   ✓ (a)
2. New cells generate from (a) Bacterial fermentation (b) Regeneration of old cells (c) Pre-existing cells (d) Abiotic materials.
   ✓ (c)
3. Match the following :

Column I	Column II
(a) Cristae	(i) Flat membranous sacs in stroma
(b) Cisternae	(ii) Infolding
(c) Thylakoids	(iii) Disc-shaped sacs in Golgi apparatus.

   ✓ (a) –(ii), (b) –(iii), (c) –(i)
4. Which of the following is correct ? (a) Cells of all living organisms have a nucleus. (b) Both animal and plant cells have a well defined cell wall. (c) In prokaryotes there are no membrane bound organelles. (d) Cells are formed *de novo* from abiotic materials.
   ✓ (c)
5. What is a mesosome in a prokaryotic cell ? Mention the function that it performs.
   ✓ Mesosome is a membrane complex formed by infolding of plasma membrane in prokaryotic cells. A mesosome may be attached to nucleoid when it is called **septal mesosome.** A mesosome free from nucleoid is known as **lateral mesosome.** Lateral mesosome is often called **chondrioid** as it is rich in respiratory enzymes. Septal mesosome takes part in separation of daughter nucleoids, formation of plasma membrane for rapid elongation and septum formation.
6. How do neutral solutes move across the plasma membrane ? Can the polar molecules also move across it in the same way ? If not, then how are these transported across the membrane ?
   ✓ **Neutral solutes** are able to directly pass through the lipid bilayer of plasma membrane as they are lipid soluble. Rate of movement depends upon concentration gradient and lipid solubility of the neutral solutes.
   Polar molecules require special hydrophilic areas for their passage. The same are provided by three types of transport mechanisms— ion, channels, permeases and ATP energised carrier proteins (for active transport).
7. Name two cell organelles that are double membrane bound. What are the characteristics of these two organelles ? State their functions and draw labelled diagrams of both.
   ✓ **Cell Organelles with Double Membrane Covering.** Mitochondria and chloroplasts (also leucoplasts, chromoplasts).
   Mitochondria. Characteristics. (i) They are cylindrical or sausage shaped cell organelles which can be stained differentially by Janus Green. (ii) The inner membrane is thrown into folds called **cristae.** (iii) Inner membrane has **ETC** (electron transport chain) as well as elementary particles or **oxysomes** ($F_0 - F_1$ particles). (iv) There are two chambers, outer and inner. (v) Inner chamber has matrix containing DNA, RNA, ribosomes, enzymes of Krebs cycle, amino acid synthesis, fatty acid synthesis, calcium and manganese. (vii) Mitochondria are simi-autonomous due to presence of their own DNA, ribosomes and RNA.
   Functions. Refer to the text.
   Chloroplasts. Characteristics. (i) They are green coloured plastids which are disc-shaped in higher plants but variously shaped in lower plants. (ii) The structural units of chloroplasts are membrane lined flattened sacs called **thylakoids.** (iii) At places the thylakoids are short and stacked. They are called **grana.** (iv) Photosynthetic pigments are located over thylakoid membranes. (v) Thylakoids possess electron transport chains and coupling factors for synthesis of ATP. (vi) Matrix of a chloroplast contains DNA, RNA, ribosomes and enzymes. Temporary starch grains and lipid containing plastoglobuli also occur. (vii) DNA, RNA and ribosomes make the chloroplasts semi-autonomous.
   Functions. Refer to the text.

8. Multicellular organisms have division of labour. Explain.

✓ Division of labour is differentiation of certain components or parts to perform different functions for increased efficiency and higher survival. Multicellular organisms often possess millions of cells. All the cells are not similar. The cells present on the surface are dead and impermeable to protect the internal cells from harsh external environment. They also form structures for offence and defence of the organism.

Every cell of a multicellular organism cannot obtain food from outside. The organism requires a system for obtaining food, its digestion and distribution. Therefore, a digestive system and system of transport are also required.

Certain cells of the body take over the function of reproduction. Others take part in repair and replacement of worn out or injured portions.

For optimum functioning of cells, a multicellular organism also comes to have an internal favourable environment.

Therefore, multicellular organisms come to have division of labour.

9. What are nuclear pores ? State their function.

✓ Nuclear pores (Callan and Tomlin, 1950) are perforations present in the nuclear envelope. Their number and size vary in different organisms and their cells. A nuclear pore may be simple channel or have extra structures like diaphragm, septum, bleb, plug of nucleoplasmin or annuli (= microcylinders). Pore having extra structures is called annulated pore or pore complex.

Functions. Nuclear pores regulate the passage of substances to the inside and outside the nucleus, *e.g.*, enzymes, RNA, ribosome units, proteins.

10. Both lysosomes and vacuoles are endomembrane structures, yet they differ in terms of their functions, comment.

✓ Endomembrane system is an intracellular membrane system which is connected by flow of membranes and materials from one part to the other with the help of vesicles. Components of endomembrane system are endoplasmic reticulum, plasma membrane, Golgi apparatus, lysosomes and vacuoles. However, each component is specialised to perform distinct functions which may be elaboration of materials supplied by another. Lysosomes are specialised to perform intracellular digestion while vacuoles are meant for storage of materials, both waste and extra.

11. Describe the structure of the following with the help of labelled diagram (i) Nucleus (ii) Centrosome.

✓ **(i) Nucleus.** It is a double membrane covered protoplasmic body that contains the genetic material. Nucleus is generally rounded or oval – elliptical in outline with a diameter of 5–25 μm. It has five parts — nuclear envelope, nucleoplasm, nuclear matrix, chromatin and nucleolus.

Nuclear Envelope. It is a double membrane covering of nucleus. The outer membrane is connected with E.R. Ribosomes often occur over its surface. A narrow perinuclear space is found between the two membranes. A number of pores called **nuclear pores** occur in the membrane. They often possess regulating structures like blebs, diaphragm, annuli, microcylinders, septum or electron dense material called nucleoplasmin. Nuclear pores allow passage of seleted materials into and outside the nucleus. (Refer Fig. 8.62).

Nucleoplasm (Nuclear Sap). It is colloidal semifluid complex having nucleosides, enzymes, proteins and factors required for functioning of genetic material.

Nuclear Matrix. It is a proteinaceous fibrous scaffold for chromatin. On the periphery, there is a dense fibrous layer of **nuclear lamina** for providing attachment sites to telomeres and mechanical strength to nuclear envelope.

Chromatin. It is a DNA-protein fibrillar complex which appears in the form of a network and is often called **chromatin reticulum**. Chromatin is dispersed throughout the nucleus. It has a narrow active hightly stained **euchromatin** part and a granular darkly stained inactive heterochromatin part. During cell division, chromatin condenses to form chromosomes.

Nucleolus. It is a rounded or slightly irregular, naked structure attached to chromatin which is specialised to synthesize ribosome subunits. Nucleolus has four parts— amorphous matrix, granular portion, fibrous portion and chromatin part.

✓ **(ii) Centrosome** (Central Apparatus). It is a naked cell organelle found in animal cells and cells of some lower plants that takes part in formation of spindle ad basal bodies of cilia or flagella. A centrosome lies near the nucleus. It has a nongranular cytoplasmic region called centrosphere and two cylindrical structures named centrioles. The two centrioles lie at right angles to each other. Each centriole has a whorl of nine **triplet fibrils** of fused microtubules that run parallel to one another but at an angle of 40°. The centre of the centriole has a proteinaceous rod called **hub**. Hub is connected

to peripheral triplets by means of proteinaceous strands known as **spokes.** A thickening called *X* is present on the spoke near the triplet. Another thickening *Y* is found nearby. *Y* is attached to *X* as well as C–A linker between the adjacent triplets. The whole complex gives a cart-wheel appearance. (Fig. 8.58).

Each centriole is surrounded by dense amorphous protoplasmic masses called **massules** or pericentriolar satellites. They function as nucleating centres for growth of new fibrils during formation of aster and daughter centrioles.

12. What is centromere ? How does the position of centromere form the basis of classification of chromosomes. Support your answer by showing the position of centromere on different types of chromosomes.

✓ **Centromere.** Centromere or primary constriction is a narrow lightly stained area of the chromosome where two chromatids are attached to each other. It also provides site over its surface for attachment of chromosome fibre. (Fig. 8.64)

Based on position of centromere, chromosomes are of four types— (i) **Metacentric.** Centromere median. (ii) **Submetacentric.** Centromere submedian. (iii) **Acrocentric.** Centromere subterminal. (iv) **Telocentric.** Centromere in the area of telomere.

13. What are characteristics of prokaryotic cells ?

✓ Refer to the text.

14. Cell is a basic unit of life. Discuss in brief.

✓ Refer to the text

TEST QUESTIONS

One Mark Questions (With Answers)

1. Who built the very first microscope ?

✓ Zacharias Janssen in 1590.

2. What are embryoids ?

✓ Embryoids are nonzygotic embryo like structures which are formed *in vitro* cultures and have the potential to develop into full fledged plants.

3. Why are the eggs usually large sized cells ?

✓ In general, eggs are large sized cells because they store food for the partial or complete development of the embryo.

4. What is the chemical constitution of cell wall matrix ?

✓ Water - 60%, Hemicellulose – 5-15%, Pectic Substances – 2-8%, Lipids – 0.5-3.0%, Proteins – 1-2%.

5. What is plasmalemma ?

✓ **Plasmalemma** or **plasma membrane** is a biomembrane that occurs on the outside of the cytoplasm in both procaryotic and eucaryotic cells.

6. Who proposed the first lamellar model ?

✓ Danielli (1935) and Davson (1935).

7. What is the major function of cell membranes in a eukaryotic cell ?

✓ The major function of cellular membranes is **compartmentalisation.**

8. Which cell organelle helps in the formation of root hair ?

✓ The formation of root hair from their mother cells is believed to take place through the agency of Golgi apparatus.

9. With which cell organelle diastole and systole are associated ?

✓ Contractile Vacuoles.

10. Which is the principal site for the development of ribosomal RNAs.?

✓ Nucleolus.

11. Does nucleoplasm possess cyclosis ?

✓ No, cyclosis or streaming is absent.

12. Who discovered the cell ?

13. Define totipotency.
14. What is meant by cell differentiation ?
15. Who proposed the cell theory ?

Two Mark Questions (With Sample Answers)

1. Write about cellular autonomy in unicellular organisms ?

   ✓ In unicellular organisms the cell has complete independent existence. It is not dependent upon any other cell for any function, material or information. The cell depends upon its own internal or intrinsic information. However, it responds to environment with which it is in direct contact. All life activities are carried out by the same cell. The division of labour is absent.

2. What are the disadvantages of multicellularity ?

   ✓ (i) Specialised cells often lose the power of division so that injury is not repaired, *e.g.*, nerve cells.

   (ii) Regeneration ability of multicellular organisms decreases with specialisation.

   (iii) Specialised cells may lose vital functions in order to carry out specific activity, *e.g.*, RBCs, sieve tube cells.

   (iv) Some unicellular organisms are immortal as their body gets distributed in their offspring. This is not so in case of multicellular organisms. Here only a few germinal cells are involved in reproduction while most cells die with the death of the organism.

3. Write a short note on primary wall ?

   ✔ **Primary Wall.** It is the first formed wall of the cell which is produced inner to the middle lamella. The primary wall is commonly thin (0.1–3.0 μm) and capable of extension. It grows by intussusception or addition of materials within the existing wall. Some cells possess only primary wall, *e.g.*, leaf cells, fruit cells, cells of cortex and pith. Primary wall consists of a number of cellulose **microfibrils** embedded in the amorphous gel-like matrix or ground substance of pectin, hemicellulose and glycoprotein.

4. Explain the structure and function of plasmodesmata with the help of a diagram ?

   ✔ Plasmodesmata are cytoplasmic bridges between adjacent plant cells which develop in the minute pores of their walls. They form a protoplasmic continuum called **symplast.** Various substances can pass from one cell to another through plasmodesmata. A plasmodesma consists of a canal lined by plasma membrane and having a simple or branched tubule known as desmotubule. Desmotubule is an extension of endoplasmic reticulum.

5. Name the two main constituents of the plasma membrane and show how they are arranged by means of a diagram.
6. Give the specific scientific terms for the following

   (a) Cluster of ribosomes found in cytoplasm.

   (b) Extensive infoldings to the inner membrane of mitochondria.

   (c) Stacks of closely packed thylakoids.

   (d) Stalked particles on the inner membrane of the mitochondria.

7. (i) Write a short note on ribosomes.

   (ii) Which organelle has a key role in the transformation and turn over of membranes within the cell?

8. How does a mitochondrion differ functionally from a chloroplast.
9. Give significance of glycocalyx.
10. What are the cell inclusions in a prokaryotic cell ?

Three Mark Questions

1. What are the advantages for an organism to have tissues instead of the one type of cells ?
2. Who proposed the Cell Theory ? Explain the main points of this theory as it stands today.
3. What is the difference between unicellular and multicellular organisms in organisation of their cells?
4. Discuss the modern concept of cell theory.
5. Enumerate the functions of biomembranes.
6. (a) Apart from nucleus, which two other cell organelles have independent DNA ?

   (b) What is the principal site of synthesis of ribosomal RNA ?

7. Distinguish between

   (a) cytoplasm and nucleoplasm; (b) chromatin and chromosome ; (c) microtubules and microfilaments.

8. Write a note on exocytosis and endocytosis.
9. Describe the structure of ribosome ?
10. Differentiate among microtubules, microfilaments and microfibrils.
11. (a) Describe the structure of centriole. ; (b) Mention the main functions of centriole.
12. (a) Define dictyosome. Point out the difference between Golgi apparatus of plant and animal cells.
    (b) Why is Golgi apparatus called Golgi apparatus.
    (c) Name an organism and cell where Golgi apparatus is absent.
13. (a) Which cell organelles are referred to as suicide bags ? Why are they given this name ?
    (b) Mention the scientific contribution of C. de Duve.
14. Write an account of lysosomes and their role in cellular metabolism.
15. Describe the structure and function of peroxisomes.
16. (a) Name the scientists who discovered mitochondria.
    (b) Which is the most indispensable in the life of a cell —mitochondria, chloroplasts or Golgi body ? Why ?
17. What are vacuoles? Name their types and functions.
18. Describe the functions of the three organelles, *viz.* Golgi bodies, chloroplasts and mitochondria.
19. Distinguish between (a) Primary wall and secondary wall ; (b) Leucoplast and chromoplast.
20. Distinguish between prokaryotic and eukaryotic cells.
21. Give the difference between cell walls of Gram-positive and Gram-negative bacteria.

Five Mark Questions

1. Describe the electron microscopic structure of cell wall and state its functions.
2. Briefly describe pinocytosis and phagocytosis. Differentiate between the two.
3. Where would the following structures be found in a cell ?
   (a) microtubules (b) thylakoids (c) F_0 -F_1 complex (d) ribosomes (e) nucleolus.
4. List the functions of rough and smooth endoplasmic reticulum and Golgi bodies.
5. Name the various types of plastids. Where do fat soluble pigments occur.
6. Describe with the help of a diagram the structure of Golgi body and state its functions.
7. (a) What is the significance of the presence of naked DNA in mitochondria?
   (b) Mitochondrial ribosomes are similar to prokaryotic ribosomes. Give the significance of this report.
   (c) Mitochondria are the centres of oxidation of respiratory substrates. Why do not they get burnt up by the released energy ?
8. (a) Briefly describe the structure of chloroplast in relation to functions.
   (b) State the chief functions of chloroplast.
9. Describe the fluid mosaic model of plasma membrane.

True or False

1. Indicate which of the following statements are true (T) or false (F).
   (a) Robert Hook discovered the nucleus.
   (b) Cells are composed of highly independent and randomly interacting components.
   (c) Virchow stated that cells arise from pre-existing cells.
   (d) The cell theory was proposed by Robert Hooke.

MULTIPLE CHOICE QUESTIONS

(1) Tubulin occurs in (a) Microtubules (b) Cilia and flagella (c) Microvilli (d) Both (a) and (b).
(2) Microtubules do not occur in (a) Mitochondria (b) Centrioles (c) Spindle fibres (d) Flagella.
(3) The term nucleolus was coined by (a) Flemming (b) Bowman (c) Fontana (d) Strasbuger.
(4) Ribosomes are granules formed of (a) rRNA + tRNA (b) mRNA + tRNA (c) rRNA + proteins (d) mRNA + proteins.
(5) Lysosomes take part in (a) Intracellular digestion (b) Extracellular digestion (c) Fat breakdown (d) Both (a) and (b).

(6) Lipid molecules of plasma membrane occur (a) Parallel (b) Scattered (c) Alternately (d) In series.

(7) Chromosome carrying centromeres at one end is (a) Metacentric (b) Submetacentric (c) Acrocentric (d) Telocentric. *(AIIMS 2002, MPPMT 2002)*

(8) Which one is present nearest to plasma membrane (a) Middle lamella (b) Primary wall (c) Secondary wall (d) Tonoplast. *(AFMC 2002)*

(9) Plasmodesmata take part in (a) Synchronous mitotic divisions (b) Cytoplasmic streaming (c) Movements of substances between cells (d) Locomotion in unicellular organisms. *(AIIMS 2003)*

(10) Welded areas between adjacent cells are (a) Desmosomes (b) Gap junctions (c) Intercellular bridges (d) Inter digitations. *(CET Chd. 2003)*

(11) Chlorophyll occurs in chloroplast (a) Inner membrane (b) Thylakoid membranes (c) Outer membrane (d) Stroma. *(CBSE 2004)*

(12) Which is common in plant and animal cells (a) Centrioles (b) Central vacuole (c) Mitochondria (d) Plastids. *(DPMT 2004)*

(13) Ion connected with forming cross bridges is (a) Na^+ (b) Ca^{2+} (c) K^+ (d) None of the above. *(Orissa 2004)*

(14) Which is not a function of vacuole in plant cell ? (a) Formation of H_2O_2 (b) Waste disposal (c) Cell elongation (d) Storage. *(Pb PMT 2005)*

(15) Arrangement of ciliary microtubules is (a) 9 + 9 (b) 9 + 3 (c) 9 + 4 (d) 9 + 2. *(RPMT 2006)*

(16) A clear zone around Golgi appratus is zone of (a) Separation (b) Transition (c) Inclusion (d) Exclusion. *(CET Chd. 2006)*

(17) Lysosomes are produced by (a) Mitochondria (b) Endoplasmic reticulum (c) Golgi bodies (d) Leucoplasts. *(BHU 2007)*

(18) Which does not occur in cell membrane (a) Glycolipids (b) Proline (c) Phospholipids (d) Cholesterol. *(CBSE 2007)*

(19) Subunits of 80S ribosomes are (a) 40 s (b) 60 s (c) 40 s and 60 s (d) None of the above. *(DPMT 2008)*

(20) Vacuole of plant cells (a) lacks membrane, contains water and excretory substances (b) is membrane bound, contains water and excretory substances (c) is membrane bound, contains storage proteins and lipids (d) lacks membrane and contains air. *(CBSE 2008)*

(21) What is true of membrane lipids and proteins ? (a) None can flip-flop (b) both can flip-flop (c) proteins can flip-flop but lipids cannot (d) lipids can rarely flip-flop but proteins cannot. *(CBSE 2008)*

(22) Middle lamella is mainly composed of (a) Calcium pectate (b) Phosphaglycerides (c) Muramic acid (d) Hemicellulose. *(CBSE 2009)*

(23) Cytoskeleton is made of (a) Callose deposits (b) Cellulose microfibrils (c) Proteinaceous filaments (d) Calcium carbonate granules. *(CBSE 2009)*

(24) Who first saw and described a live cell (a) Matthias Schleiden (b) Theodore Schwann (c) Anton von Leeuwenhock (d) Rudolf Virchow. *(HP PMT 2010)*

(25) Plasma membrane consists mainly of (a) Proteins embedded in a phospholipid bilayer (b) Protein embedded in a polymer of glucose molecules (c) Proteins embedded in a carbohydrate bilayer (d) Phospholipids embedded in protein bilayer. *(CBSE 2010)*

(26) Structural element of chromatin is (a) histone (b) acid protein and DNA (c) nucleosome (d) nuclear matrix. *(WB 2011)*

(27) Animal cells do not possess (a) plasmodesmata (b) centriole (c) 80S ribosomes (d) all the above. *(MP PMT 2011)*

(28) Which one does not differ in *Escherichia coli* and *Chlamydomonas* (a) cell wall (b) cell membrane (c) ribosomes (d) chromosomal organisation. *(CBSE 2012)*

(29) Which one is an organelle within an organelle (a) ER (b) Mesosome (c) Peroxisome (d) Ribosome. *(CBSE Mains 2012)*

(30) Endoskeleton of cell is (a) cell wall (b) Mitochondria (c) Endoplasmic reticulum (d) Cytoplasm. *(MP PMT 2013)*

(31) Major site for synthesis of lipids is (a) Symplast (b) SER (c) RER (d) Nucleoplasm. *(NEET 2013)*

(32) Golgi complex play a major role in (a) Post translational modification of proteins and glycosidation of lipids (b) Trapping light and transforming it into chemical energy (c) Digesting proteins and carbohydrates (d) An energy transforming organelle. *(NEET 2013)*

(33) The solid linear cytoskeletal elements having a diameter of 6nm and made up of a single type of monomer are known as (a) microfilaments (b) intermediate filaments (c) lamins (d) microtubules. *(CBSE 2014)*

(34) Protoplast is a cell (a) without plasma membrane (b) without nucleus (c) undergoing division (d) without cell wall. *(CBSE 2015)*

(35) GERL is formed of (a) Golgi body, endoplasmic reticulum, ribosome and lysosome (b) Golgi body, endoplasmic reticulum and lysosome (c) Golgi body, endoplasmic reticulum and ribosome (d) Golgi body, ribosome and lysosome. *(Chhatisgarh 2015)*

(36) Microtubules are constituents of (a) centrosome, nucleosome and centrioles (b) cilia, flagella and peroxisomes (c) spindle fibres, centrioles and cilia (d) centrioles, spindle fibres and chromatin. *(NEET 2016)*

(37) A cell organelle containing hydrolytic enzymes is
(a) Mesosome (b) Lysosome (c) Microsome (d) Ribosome. *(NEET 2016)*

(38) Which of the following cell organelles is responsible for extracting energy from carbohydrates to form ATP ? (a) Lysosome (b) Ribosome (c) Chloroplast (d) Mitochondrion. *(NEET 2017)*

Assertion and Reason Type Questions

1. **Assertion :** A cell membrane shows fluid behaviour.
   Reason : A membrane is a mosaic of tipids and proteins.
   (A) (B) (C) (D) *(AIIMS 2008)*
2. **Assertion :** Mitochondria and chloroplasts have their own genome.
   Reason : Endoplasmic reticulum and Golgi body are the cell organelles which have their own DNA.
   (A) (B) (C) (D) *(AIIMS 2013)*
3. **Assertion :** Gap Junctions perform cementing function to keep the neighbouring cells together.
   Reason : Tight junctions facilitate the cells to communicate with each other by connecting the cytoplasm of adjoining cells for rapid transfer of ions, small and big molecules.
   (A) (B) (C) (D) *(AIIMS 2016)*

ANSWERS

True & False

1. (a) —F (b) —F (c) —T (d) —F

Multiple Choice Questions

(1) —d (2) —a (3) —b (4) —c (5) —d (6) —a (7) —d (8) —c (9) —a (10) —a
(11) —b (12) —c (13) —b (14) —a (15) —d (16) —d (17) —c (18) —a (19) —c (20) —b
(21) —d (22) —a (23) —c (24) —c (25) —a (26) —c (27) —a (28) —b (29) —d (30) —c
(31) —b (32) —a (33) —a (34) —d (35) —b (36) —c (37) —b (38) —d

Assertion and Reason Type Questions

(1) —A (2) —C (3) —D

Chapter

9

Biomolecules

THEORY–a quick rundown

All the elements present in a sample of earth's crust are also present in a sample of living tissue. However, a closer examination reveals that the relative abundance of carbon and hydrogen with respect to other elements is higher in any living organism than in earth's crust.

A Comparison of Elements Present in Non-living and Living Matter

Element	% Weight of	
	Earth's crust	Human body
Hydrogen (H)	0.14	0.5
Carbon (C)	0.03	18.5
Oxygen (O)	46.6	65.0
Nitrogen (N)	Very little	3.3
Sulphur (S)	0.03	0.3
Sodium (Na)	2.8	0.2
Calcium (Ca)	3.6	1.5
Magnesium (Mg)	2.1	0.1
Silicon (Si)	27.7	Negligible

THE CELLULAR POOL

Various types of chemicals or molecules present in the living organisms are known as biomolecules and collection of different types of biomolecules, compounds or ions present in a cell are called **the cellular pool**. Cellular pool has two phases:

(a) **Aqueous phase.** It contains chemicals dispersed in water forming either true solution or colloidal solution.

(b) **Non-aqueous phase.** It contains chemicals deposited in various structures like chromatin, cell membrane and cell wall.

Cellular pool consists of two types of biomolecules— Inorganic and organic. Inorganic biomolecules are— salts, mineral ions and water. Main organic compounds are— carbohydrates, lipids, amino acids, proteins, nucleic acids, nucleotides, hormones and vitamins.

Chemicals of cellular pool are obtained from outside through selective intake by cells through membranous covering of cell organelles and plasma membranes. The membranes possess selective permeability and retentivity. Chemicals of cellular pool function as raw material for various reactions of cell organelles and cell. Depending upon their molecular weight and solubility, biomolecules are of two types—

(a) **Micromolecules.** They are small sized chemicals having low molecular weight, and higher solubility. They include water, gases, minerals, sugars, amino acids and nucleotides.

(b) **Macromolecules.** They are large sized complex chemicals having a high molecular weight, low solubility and complex conformation. They include four classes of organic compounds *viz.*, carbohydrates, lipids, proteins and nucleic acids. Except lipids, other macromolecules are formed by the polymerization of monomer subunits. Three-dimensional shapes of macromolecules enable them to function as structural components, nutrient stores, energy source, enzymes, molecular messenger and storehouse of genetic information etc.

How to Analyse Chemical Composition?

One has to perform a chemical analysis. We can take any living tissue (a vegetable or a piece of liver, etc.) and grind it in trichloroacetic acid (Cl_3CCOOH) using a mortar and a pestle. We obtain thick slurry. If we were to strain this through a cheesecloth or cotton we would obtain two fractions. One is called the filtrate or more technically, the acid-soluble pool, and the second, the retentate or the acid-insoluble fraction. Scientists have found thousands of organic components in the acid-soluble pool.

Living organisms have also got inorganic elements and compounds in them. How do we know this? A slightly different but destructive experiment has to be done. One weighs a small amount of a living tissue (say a leaf or liver and this is called wet weight) and dries it. All the water evaporates. The remaining material gives dry weight. Now if the tissue is fully burnt, all the carbon compounds are oxidized to gaseous form (CO_2, water vapour) and are removed. What is remaining is called 'ash'. This ash contains inorganic elements (like calcium, magnesium etc.) Inorganic compounds like sulphate, phosphate, etc., are also seen in the acid-soluble fraction. Therefore, elemental analysis gives elemental composition of living tissues in the form of hydrogen, oxygen, chlorine, carbon etc. while analysis for compounds gives an idea of the kind of organic and inorganic constituents present in living tissues.

BIOMACROMOLECULES

There is one feature common to all those compounds found in the acid soluble pool. They have molecular weights ranging from 18 to around 800 daltons (Da) approximately.

The acid insoluble fraction has only four types of organic compounds, *i.e.*, proteins, nucleic acids, polysaccharides and lipids. These classes of compounds with the exception of lipids have molecular weights in the range of ten thousand daltons and above. For this very reason, biomolecules, *i.e.*, chemical compounds found in living organisms are of two types. One, those that have molecular weights less than one thousand Dalton and are usually referred to as **micromolecules** or simply biomolecules while those which are found in the acid insoluble fraction are called **macromolecules** or **biomacromolecules**.

The molecules in the insoluble fraction with the exception of lipids are polymeric substances. Then why do lipids, whose molecular weights do not exceed 800 Da, come under acid insoluble fraction, *i.e.*, macromolecular fraction? Lipids are indeed small molecular weight compounds and are

present not only as such but also arranged into structures like cell membrane and other membranes. When we grind a tissue, we are disrupting the cell structure. Cell membrane and other membranes are broken into pieces, and form vesicles, which are not water-soluble. Therefore, these membrane fragments in the form of vesicles get separated along with the acid insoluble pool and hence in the macromolecular fraction. Lipids are not strictly macromolecules.

Average Composition of Cells	
Component	*% of the total cellular mass*
Water	70 – 90
Proteins	10 – 15
Carbohydrates	3
Lipids	2
Nucleic acids	5 – 7
Ions	1

One of the greatest discoveries ever made was the observation that all these biomolecules have a turn over. This means that they are constantly being changed into some other biomolecules and also made from some other biomolecules.

The Living State

The most important fact of biological systems is that all living organisms exist in a steady state characterized by concentration of each of these biomolecules. These biomolecules are in a metabolic flux. Any chemical or physical process moves spontaneously to equilibrium. The steady state is a non-equilibrium state. One should remember from physics that systems at equilibrium could not perform work. As living organisms work continuously, they cannot afford to reach equilibrium. Hence the living state is non-equilibrium steady state to be able to perform work; living process is a constant effort to prevent falling into equilibrium. This is achieved by energy input. Metabolism provides a mechanism for the production of energy. Hence the living state and metabolism are synonymous. Without metabolism there cannot be a living state.

CARBOHYDRATES

Carbohydrates are polyhydroxy aldoses, ketoses and their condensation products. Aldoses bear terminal aldehyde or –CHO group (*e.g.*, xylose, ribose, glucose, galactose) while ketoses have an internal ketone or –CO⁻ group (*e.g.*, ribulose, xylulose, fructose, erythrulose). Carbohydrate is a hydrate of carbon or $C_n(H_2O)_n$ in which *n* is an integer ranging from 3–7. Some carbohydrates contain additional atoms of sulphur or nitrogen. Carbohydrates are directly produced during photosynthesis of autotrophic plants, thus constituting major part of dry weight of plant (upto 80%). They are called saccharides, because their basic components are sugars.

Carbohydrates are of two types – small and large. Small carbohydrates have low molecular weight, sweet taste and they are soluble. They are further differentiated into monosaccharides, derived monosaccharides and oligosaccharides. They are also called sugars. Large carbohydrates are called polysaccharides.

Small Carbohydrates

(A) Monosaccharides

They are sugars or simple carbohydrate monomers, which cannot be hydrolysed further into smaller components. General formula for monosaccharides is $C_nH_{2n}O_n$. Depending upon number of carbon atoms, they are of five types—

(a) **Trioses.** These are the carbohydrates having 3 carbon atoms ($C_3H_6O_3$) *e.g.*, dihydroxyacetone, glycerose (glyceraldehyde).

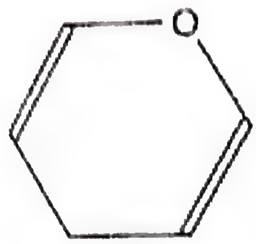
(b) **Tetroses.** Carbohydrates having four carbon atoms ($C_4H_8O_4$) *e.g.*, orthyrose, threose.

(c) **Pentoses.** Carbohydrates with 5 carbon atoms ($C_5H_{10}O_5$) are called pentoses, *e.g.*, Ribose, Xylose, Ribulose, Arabinose and deoxyribose. Deoxyribose is an exception having a formula of $C_5H_{10}O_4$.

(d) **Hexoses.** Carbohydrates having six carbon atoms ($C_6H_{12}O_6$) *e.g.*, Glucose, Fructose, galactose, Mannose.

(e) **Heptoses.** These are the carbohydrates having seven carbon atoms ($C_7H_{14}O_7$), *e.g.*, Sedoheptulose, Glucoheptose, galactoheptose.

Pentoses and hexoses exist in both open chain as well as ring forms. Ring forms are of two types— Pyranose and furanose. **Pyranose** has hexagon structure with 5 carbons and one oxygen. While **Furanose** has a pentagon structure with 4 carbon and one oxygen.

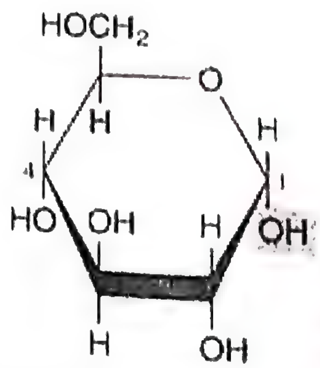


Pyranose

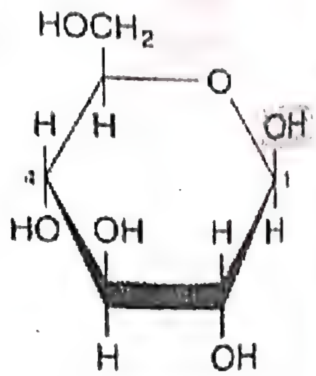
Furanose

Furanose and pyranose forms further are of two types each *viz*- α and β (called anomers). In α **form** the hydroxyl group near the oxygen atom of ring *i.e.*, carbon atom no.1 is written below while in **β from** it is written above.

Many monosaccharides have asymmetric carbons and are able to rotate polarized light to right side (d or dextrorotatory, +) or left side (l or levorotatory, Θ). Among trioses with aldehyde group, carbon atom in second position is asymmetric one, giving two optically active forms *viz.* d-glycerose and l-glycerose. (It is to be noted that Capital L, D and small l, d do not have the same meaning). Small l and d stand for optical rotation which has to be determined experimentally. Capital L and D refer to relative configuration of OH group around the lowest chiral (asymmetric) centre, the carbonyl group (aldehyde) being at the top. It is termed as D if OH is on the right side and L if OH is on the left side. Glyceraldehyde molecule is taken as the standard to which configurations of the carbohydrates are compared. In case of amino acids position of NH_2 (instead of OH) is observed. It has been found that all the α–amino acids forming proteins have L-configuration. Amongst sugars D-sugars are more common. It should also be remembered that D family may contain leavo or dextro forms of different sugars/amino acids and same is true for L family also).



α-D-Glucopyranose
(α-anomer)

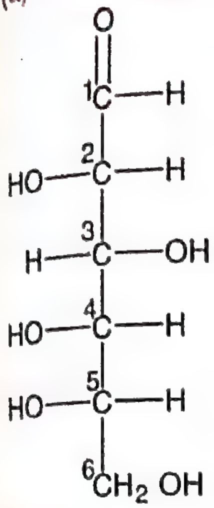


β-D-Glucopyranose
(β-anomer)

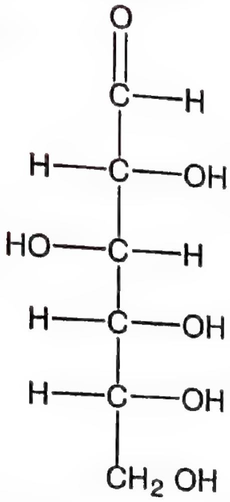
Structures of other important monosaccharides

1. Glucose

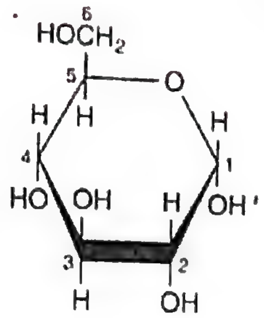
(a) L-Glucose



(b) D-Glucose

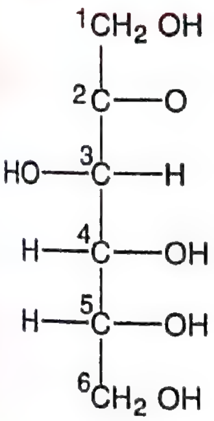


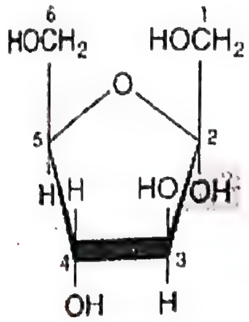
(c) Ring form



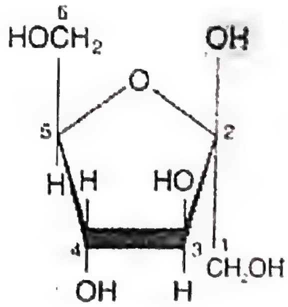
2. Fructose

D-Fructose

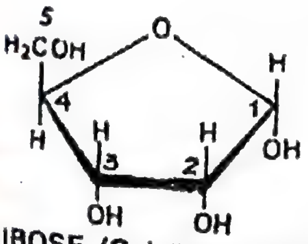




α-D-Fructofuranose



β-D-Fructofuranose



RIBOSE (C_5) RING FORM

Two sugars which differ from one another only in the configuration around one specific carbon are called **epimers** of each other, *e.g.*, D-glucose and D-galactose are epimers with respect to C-4. Similarly D-glucose and D-mannose differ only in stereochemistry at C-2.

Sugars with same structural formula but differing in spatial configuration are known as **isomers**, e.g., L and D forms of glucose. Presence of asymmetric carbon atoms (carbon atoms attached to four different atoms or groups) allows the formation of isomers.

Amongst sugars D-isomers are more common.

Monosaccharides of physiologic importance

1. **D-ribose.** It is the structural element of nucleic acids and coenzymes *e.g.*, ATP, NAD, NADP etc. It is formed as an intermediate in pentose phosphate pathways.

2. **Fructose.** It is sweetest of all naturally occurring sugars and is also called fruit sugar because of its common occurrence in fruits (except in grapes). Nectar, honey and seminal fluid also contain fructose. Honey is largely a hydrolytic product of sucrose and presence of fructose accounts for greater sweetness of honey. Fructose is also called laevolose because of its laevorotatory nature (however, it belongs to D-family).

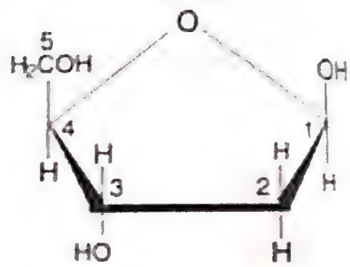
3. **Glucose.** It is "sugar" of the body, which is carried by blood, and principle one used by tissue. Also called 'blood sugar'. It is formed by hydrolysis of starch, cane sugar, maltose and lactose. It is also known as grape sugar, corn sugar and dextrose. It is the main respiratory substrate and hence forms immediate source of energy.

4. **Galactose.** It is formed by hydrolysis of lactose. It can be changed to glucose in the liver. It is synthesized in the mammary glands to make lactose of milk.

(B) Derived Monosaccharides

Monosaccharides are modified to form a number of different substances. Various such derivatives are

(a) **Deoxy sugars.** They are formed by the deoxygenation where hydroxyl group is replaced by a hydrogen atom *e.g.*, deoxygenation of ribose produce deoxyribose which is a constituent of deoxyribotide found in DNA.



DEOXYRIBOSE (C_5)

(b) **Amino sugars.** Here hydroxyl group of a sugar is replaced by an amino or an acetylamino group *e.g.*, Glucosamine, a product of hydrolysis of chitin, and galactosamine found in chondroitin sulphate.

(c) **Sugar Acids.** They are produced by oxidation of aldehydic carbon, terminal hydroxyl carbon or both. Ascorbic acid, glucuronic acid and galacturonic acid are sugar acids.

(d) **Sugar alcohol.** Aldoses and ketoses may be reduced at carbonyl carbon to yield corresponding sugar alcohols *e.g.*, D-glucose yields D-sorbitol, D-mannose yields D-mannitol. Mannitol is storage alcohol in some fruits and brown algae.

- Molisch test is +ve with all sugars.
- Osazones are crystalline derivatives of sugars. Osazones are not formed by sucrose.

(C) Oligosaccharides

They are small carbohydrates formed by condensation of 2-9 monosaccharides. Depending upon the number of monosaccharide molecules condensed to form oligosaccharides, the latter are known as disaccharides (*e.g.*, maltose, sucrose and lactose), trisaccharides, tetrasaccharides (*e.g.*, stachyose), pentasaccharides, hexasaccharides. Like polysaccharides oligosaccharides belong to the category of compound carbohydrates.

I. **Disaccharides.** They are the smallest and the commonest oligosaccharides. They are formed by the condensation of two monosaccharide molecules. Hexosan disaccharides are the best known, *e.g.*, sucrose, maltose, lactose, trehalose.

1. **Trehalose.** It is found in some fungi and haemolymph of some insects. It is a disaccharide made up of two glucose units. Both the glucose molecules are in α - form and the linkage is $1\rightarrow1$.

2. **Sucrose.** It is the most abundant disaccharide. Also called commercial sugar. Most of it is obtained from sugar cane along with sugar beet. It is formed by condensation of one molecule each of glucose and fructose with reaction releasing a molecule of water. In sucrose, fructose occurs

in the furanose form while glucose is in pyranose state. Union is in aldehyde region of glucose and ketone region of fructose. The hydrolysis of sucrose to D-glucose and D-fructose is accompanied by a change in optical rotation from dextro to levo. Thus, hydrolysed sucrose is sometimes called **invert sugar** and the enzyme that catalyses the process is also called invertase.

3. **Maltose or malt sugar.** It is found in detectable amounts in germinating seeds and tissues where starch is being broken down. Maltose is a reducing sugar formed by condensation of two alpha D-glucose units.

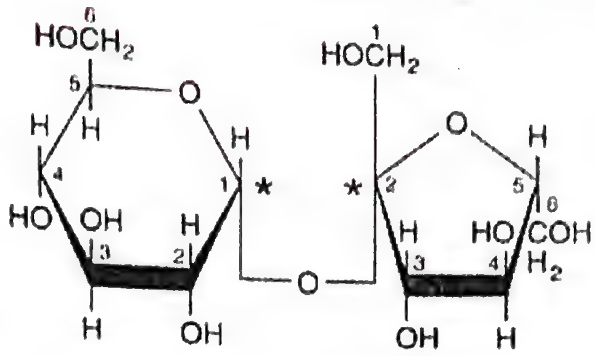
4. **Lactose or milk sugar.** It is found naturally in milk, which is formed inside mammary glands by condensation of two hexose sugars, glucose and galactose. Souring of milk is due to conversion of lactose into lactic acid.

5. **Cellbiose.** It is a disaccharide formed during hydrolysis of cellulose. It has two glucose molecules, which have β-1→4 linkage.

6. **Isomaltose.** It is made up of two glucose units having α -1→ 6 linkage.

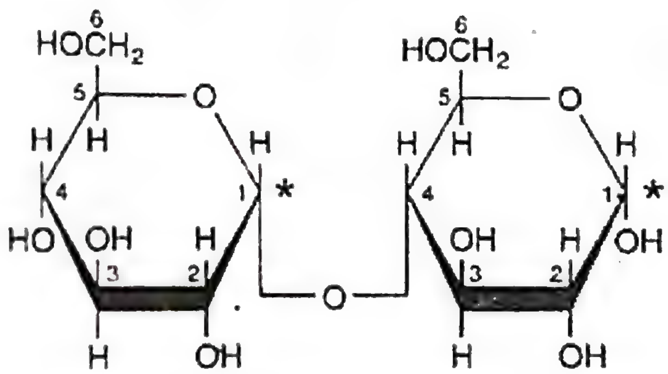
II. **Trisaccharide.** Raffinose, a trisaccharide, is a reducing sugar, which is formed of glucose, fructose and galactose. It is found in sugar beets. Melezitose formed of glucose+ fructose+ glucose is another trisaccharide found in sap of some coniferous trees.

Sucrose



O-α-D-Glucopyranosyl-(1→ 2)-β-D-fructofuranoside

Maltose



O-α-D-Glucopyranosyl-(1→ 4)-α-D-glucopyranose

Sweetening index of sucrose, maltose and lactose is respectively 100, 32 and 16, 170 for fructose and 40,000 for saccharin.

Reducing sugars. These are the sugars, which can reduce Cu^{2+} ions to Cu^{+} state. This property is seen in all saccharides with free aldose or ketose groups. All monosaccharides are reducing sugars. Amongst disaccharides sucrose is non-reducing because both aldose group of glucose and ketose of fructose are lost due to formation of glycosidic bond between the two. Trehalose is also a non- reducing sugar. Other disaccharides *e.g.*, maltose and lactose possess reducing groups thus called reducing sugars. This reaction is useful in detection of glucose in urine. Benedicts test is commonly used test for sugar detection in urine. Benedict's reagent contains cupric sulphate in a solution of Na_2CO_3 and Sodium citrate. Positive test is indicated by formation of brick red precipitates of cuprous oxide.

Another test used is Fehling's test. Fehling's reagent contains cupric sulphate in solution of NaOH and sodium potassium tartarate. Positive test is indicated by formation of yellow precipitates of cuprous oxide.

Functions of small Carbohydrates

1. Trioses, glyceraldehyde and dihydroxy acetone, are important intermediates of both respiratory and photosynthetic pathways.

2. Erythrose, a tetrose monosaccharide is an intermediate of respiratory and photosynthetic pathways. It also acts as a raw material for synthesis of lignin, anthocyanines and some amino acids e.g., tyrosine, phenylalanine.

3. Pentose sugars, xylose and arabinose form polymers which are constituents of hemicellulose.

4. Ribulose 1, 5 biphosphate is the acceptor of carbon dioxide in photosynthesis.

5. Sedoheptulose, a heptose sugar, is an intermediate of respiratory and photosynthetic pathways.

6. Ribose is found in FAD, NAD, NADP and ATP.

7. Oligosaccharides attached to cell membranes take part in recognition, attachment and antigen specificity.

8. Glucose is polymerized to produce storage carbohydrates, starch in plants and glycogen in animals.

Carbohydrate Bonds

The subunits of disaccharide and polysaccharide are linked by means of glycosidic bonds in which carbon of one sugar unit is bound to the oxygen atom of hydroxyl of an adjacent sugar unit. Maltose is formed by a glycosidic bond between carbon-1 of one glucose to carbon-4 of second glucose molecule. Lactose is formed by bond between C_1, of galactose and C_4 of glucose while sucrose forms by bond between C_1 of glucose and C_2 of fructose.

In glycosidic bond formation, one carbon gives up its OH group and other loses hydrogen from its OH group thus forming an H_2O molecule. This reaction is known as dehydration synthesis.

POLYSACCHARIDES

They are complex carbohydrates formed by polymerization of large number of monosaccharide monomers. They are also called glycans. They are long chained and chains may be branched or unbranched. Depending upon the composition, polysaccharides are of two types

(a) **Homopolysaccharides or homoglycans.** They are complex carbohydrates formed by polymerization of only one type of monosaccharide monomers, *e.g.*, starch, glycogen and cellulose are composed of one type of monosaccharide, glucose. Depending upon the monosaccharide unit involved polysaccharides can be:- (i) Glucan,— made of glucose, (ii) Fructan— made up of fructose, (iii) Xylanmade up of xylose, (iv) Galactan— made up of galactose and (v) Araban– made up of arabinose.

(b) **Heteropolysaccharides or heteroglycans.** These are produced by condensation of either monosaccharide derivatives or more than one type of monosaccharide monomer, *e.g.*, arabanogalactans etc.

In a polysaccharide chain (say glycogen), the right end is called the reducing end and the left end is called the non-reducing end. Starch forms helical secondary structures. In fact, starch can hold I_2 molecules in the helical portion. The starch-I_2 is blue in colour. Cellulose does not contain complex helices and hence cannot hold I_2.

Polysaccharides typically contribute to structural support and protection and serve as nutrient and energy stores. During polysaccharide formation, at each condensation, a molecule of water is released which reduces the bulk, makes polysaccharide almost insoluble thus making them ideal for storage and as structural component. Being large sized they are unable to pass through cell membrane. Passage is allowed through active process. Unlike sugars, polysaccharides are not sweet. Polysaccharides are of 3 main types— storage, structural and mucopolysaccharides.

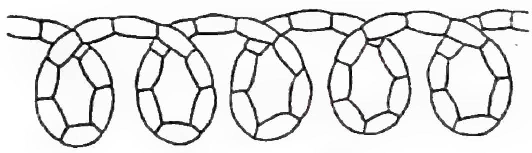
A. Food Storage Polysaccharides

These polysaccharides serve as reserve food. They are hydrolysed at the time of need and sugars thus released are made available to the living cells for energy production and biosynthetic activity. Two main types of storage polysaccharides are :

1. **Starch.** Starch is a polymer of glucose, and occurs in many plants as storage foods. It may be found in the leaves, stem, roots, fruits, and seeds, where it is present in greater concentration. Starchy food is mainstay of our diet. Large amounts are present in cereals *e.g.*, wheat, rye, rice, corn and barley, in potatoes, in legumes, in banana and in nuts. Starch is a polyglucan homosaccharide and is formed as an end product of photosynthesis. It is stored either inside chloroplasts or special leucoplasts called amyloplasts.

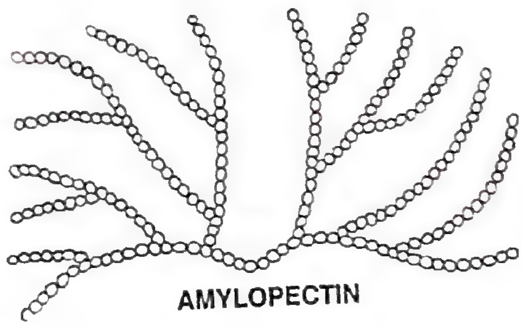
Starch occurs in the form of microscopic granules called **starch grains** which may occur singly or in groups. They may be round oval, polygonal or rod shaped in outline. Each starch grain has a number of shells or layers arranged in concentric or eccentric fashion around a common point called hilum.

Starch consists of two components amylose and amylopectin.



AMYLOSE

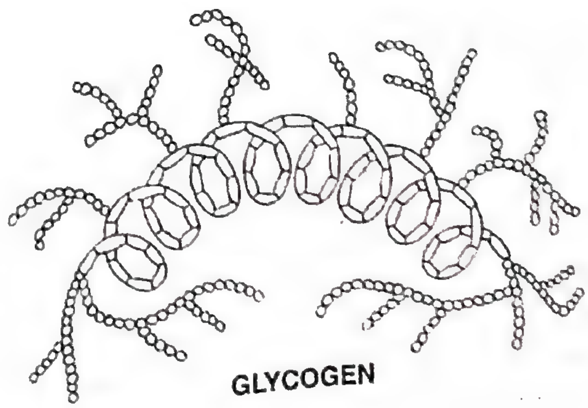
(a) **Amylose.** It constitutes 15 to 20% of starch. It is more soluble in water. Amylose gives blue colour with dilute iodine solution. It is formed by the condensation of 250-300 molecules of α-D glucose (pyranose form) units linked by α 1-4 linkage that is link between carbon atom 1 of one glucose and carbon atom 4 of other glucose. Amylose is in the form of a continuous straight but helically arranged chain where each turn contains about six glucose units.



AMYLOPECTIN

(b) **Amylopectin.** It constitutes about 80 to 85% of starch. It is insoluble in water but can absorb water and swell up. It gives reddish-violet colour with iodine solution. Amylopectin has a highly branched structure formed by polymerization of α- D glucose (pyranose form) units. Amylopectin contains about 2000-200,000 glucose units. Straight chain has α 1-4 glycosidic linkage and at intervals of 24–30 residues there is branching which involves α 1-6 glycosidic linkage *i.e.*, carbon atom 6 of glucose residue of straight chain is linked to the carbon atom 1 of the first glucose unit of side chain. Starch, whether it is in the form of amylose or amylopectin, is not a reducing sugar. It is because of the inability of the ring to open up.

Dextrins are substances formed in course of hydrolytic breakdown of starch. Limit dextrins are the first formed products as the hydrolysis of starch proceeds.



GLYCOGEN

2. **Glycogen.** Glycogen is the reserve carbohydrate of animals hence it is also called 'animal starch'. It is also found in fungi, yeasts, oysters and other shellfish. In higher animals glycogen is stored in the liver and muscles from where it is readily available as immediate source of energy. It appears as ellipsoid flattened granules that lie freely inside

the cells. Molecular weight of glycogen varies from 1,000,000 to 4,000,000. It is not readily soluble in water and forms an opalescent solution. Glycogen gives a deep-red colour with iodine solution.

Glycogen has a complex structure of highly branched chains. It is a polymer of D-glucose units and resembles amylopectin. Straight chain is formed by α 1-4 glycosidic linkage between glucose units and it is helically twisted with each turn having six glucose units. Branching occurs after every 12-14 glucose units and involve α 1-6 glycosidic linkage. Glycogen is more extensively branched and more compact than starch.

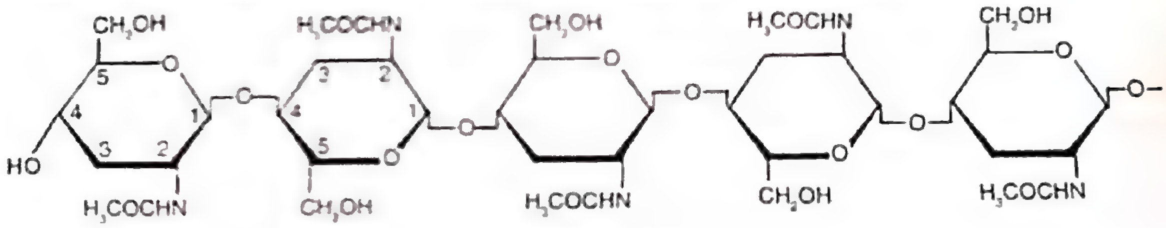
3. **Inulin.** Inulin is a fructan storage polysaccharide found in tubers and roots of dahlias, dandelions and in bulbs of onion and garlic. It is a white tasteless powder and gives no colour with iodine. It is readily soluble in warm water. It is not metabolized in human body and is readily filtered through the kidney thus useful in physiological investigation for determination of GFR. It is also used for estimation of body water volume.

B. Structural Polysaccharides

They take part in forming the structural frame work of the cell walls in plants and skeleton of animals. They are of two main types—

1. **Chitin.** It is the second most abundant organic substance. Chitin is a homopolysaccharide* found as the structural component of fungal walls, and exoskeleton of arthropods. Being soft and leathery, chitin provides both strength and elasticity. On impregnation with certain proteins and calcium carbonate it becomes hard.

Basic unit in chitin is N-acetyl glucosamines, which are joined together by β 1-4 linkages. Chitin has an unbranched configuration. Molecules occur parallel to each other and are held together by hydrogen bonds. Like cellulose, chitin is also indigestible by vertebrates.



Structure of Chitin

2. **Cellulose.** It is the chief constituent of woody fibrous portion of plant material and is most abundant of carbohydrates in nature. It is a fibrous homopolysaccharide with high tensile strength. Tunicin of tunicates, also called animal cellulose, is related to cellulose. It forms 50% of carbon found in plants. Cotton fibers have 90% of cellulose while wood contains 25-50% cellulose.

Cellulose molecules have unbranched and linear chains containing 6000 or more β D-glucose molecules. These molecules are united by β 1-4 linkages. Thus alternate glucose molecules lie at 180^0 to each other and hydroxyl groups of glucose units project in all directions. Cellulose molecules do not occur singly, instead number of chains are arranged in close antiparallel fashion. Parallel cellulose molecules are held together by hydrogen bonds between hydroxyl groups attached to carbon atoms 3 and 6. Molecular weight of cellulose ranges between 0.5 to 2.5 millions. About 2000 cellulose chains or molecules are packed together to form a microfibril.

Cellulose is a very stable insoluble compound. Being main constituent of plants it forms a considerable part of our vegetable food. Herbivorous animals with the help of bacteria, can utilize a considerable proportion of the cellulose ingested, but in human beings no cellulose splitting enzyme is secreted by G.I mucosa, so it is of no nutritional value. Only advantage in human diet is that it adds bulk to the intestinal contents thus stimulating peristalsis and elimination of indigestible food

*According to Harper, but according to NCERT it is included in heteropolysaccharide.

residues. (Being a polymer of β-glucose, cellulose is not acted upon by amylases present in human digestive juices).

Importance of Cellulose

1. An important constituent of diet for cows and buffaloes. Their stomach contains microorganisms capable of digesting cellulose. Termites and snails also have cellulose-splitting microorganisms in their gut.
2. Cellulose rich wood is employed in building furniture, tools, sports article and in production of paper.
3. Microbes are used in producing soluble sugars from cellulose, which are then allowed to undergo fermentation for obtaining ethanol, acetone, methane etc.
4. Depending upon percentage of cellulose present in fibres, latter are used in textiles, preparation of sacs or ropes.
5. Cellulose acetates are used in preparing fibres for double knits, tericot, wrinkle proof and moth proof clothing. Other uses of acetates include-preparation of cigarette filters, plastic and shatter proof glass.
6. Cellulose nitrate is used in propellant explosives.
7. Carboxymethyl cellulose is used as an emulsifier and smoothening reagent of ice creams, cosmetics and medicines.
8. Rayon and cellophane are chemically similar to cellulose xanthate.

3. **Agar.** It is a polysaccharide occurring as a natural component of seaweeds. It is made up of sulphated galactose units. It dissolves in hot water and sets to a gel on cooling like cellulose, it is not digested in human and adds bulk to the faeces (roughage value) hence used as laxative in constipation. In microbiology it is used in agar plate for culture of bacteria. It is obtained from Gracilaria, Gelidium and Gelidiella.

C. Mucopolysaccharides (Heteropolysaccharides or Heteroglycans or Glycosaminoglycans)

Mucopolysaccharides are polysaccharides built up of repeating disaccharide unit, generally composed of an amino sugar (either glucosamine or galactosamine, which may or may not be sulphated) and a uronic acid (glucuronic acid or iduronic acid).

Mucopolysaccharides thus are heteropolysaccharides *i.e.*, they are made up of more than one type of monosaccharides. Most of the mucopolysaccharides are structural components of the connective tissue. Mucopolysaccharides are viscous and good lubricants and shock absorbers. Mucopolysaccharides occur inside the plant cell walls; outside the cells or bodies of bacteria, blue green algae and many aquatic plants; cementing layer between cells; inside body fluids, connective tissues and cartilages.

Important Mucopolysaccharides or Glycosaminoglycans

1. **Hyaluronic acid.** This is the most abundant mucopolysaccharide in body. It consists of repeating dissacharide unit containing glucuronic acid + N-acetyl glucosamine. This is found in synovial fluid of joints, vitreous humour of eye, cell membranes and skin. Its firm, gel like consistency prevents bacterial attack. Hyaluronidase, an enzyme present in many bacteria cleaves hyaluronic acid thus permitting infection to spread. Hyaluronidase, for this reason, is sometimes referred to as spreading factor.

2. **Chondroitin sulphate.** It consists of repeating disaccharide unit containing glucuronic or iduronic acid and sulphated acetyl galactosamine. It is present in skin, cartilages, tendons, cardiac valves, bone and cornea.

3. **Keratan sulphate.** It consists of repeating disaccharide unit containing galactose + N-acetylglucosamine + sulphuric acid. It is found in costal cartilage and cornea.

4. **Heparin.** This is a naturally occurring blood anticoagulant produced in body by mast cells. It consists of repeating disaccharide unit containing glucosamine and glucuronic or iduronic acid. Most of the glucosamine molecules are sulphated.

5. **Heparan sulphate.** This is present throughout the cell surfaces and its composition is similar to heparin, with difference being that it contains lower content of iduronic acid but more glucuronic acid and fewer sulphate groups. Present in intima of arterial wall. Like heparin it is also capable of accelerating the action of antithrombin III, but it is much less potent than heparin.

6. **Dermatan sulphate.** It consists of iduronic acid and N-acetyl galactosamine and is widely distributed in animal tissues. Present in the intima of arterial wall. It appears to be the major glycosaminoglycans synthesized by arterial smooth muscle cells. As these smooth muscles are those that proliferate at the atherosclerotic lesion in arterial vessels, dermatan sulphate plays a significant role in development of the atherosclerotic plaque.

Colours given by carbohydrates with iodine solution

(i) Starch – blue colour
(ii) Amylose – blue colour
(iii) Amylopectin – red colour
(iv) Glycogen – red colour
(v) Inulin – no colour
(vi) Cellulose - no colour

LIPIDS

Lipids are fatty acid esters of alcohols and related substances, which are insoluble in water but get dissolved in a number of nonpolar organic solvents *e.g.*, ether, benzene, chloroform, acetone etc. In water they get uniformly dispersed in the form of minute droplets called emulsion. Lipids are made up of carbon, hydrogen and sometimes oxygen. Oxygen content is always small as compared to hydrogen and carbon. Phosphorus, Sulphur and nitrogen may be present in small amounts.

Fatty acids

Fatty acids are basic component of all lipids. They are organic acids having hydrocarbon chains that end in a carboxylic group (—COOH). The hydrocarbon chain may be methyl or ethyl or higher number of $-CH_2$ groups. Hydroxyl group may be present in some fatty acids. Hydrocarbon chain of fatty acid may be straight or have ring structure. Common fatty acids have 16 or 18 carbons. Fatty acids with <14 or >20 carbon atoms are uncommon. Most fatty acids have an even number of carbon atoms.

Plants can manufacture all types of fatty acids. Animals lack the mechanism to synthesise three fatty acids *viz.*, Linoleic, linolenic and arachidonic acid, known as **essential fatty acids**. These fatty acids must be present in the animal diet. These essential fatty acids occur in most edible oils like sunflower, groundnut, cottonseed, and coconut oil. The essential fatty acids are polyunsaturated fatty acids having two or more double bonds. Linoleic acid and linolenic acid are 18 carbon fatty acid derivatives of stearic acid while arachidonic acid is 20 carbon fatty acid derivative of arachidic acid. Mammalian tissue can convert linoleic acid to linolenic and arachidonic acids making linoleic acid. the only fatty acid, which is absolutely indispensable. Arachidonic acid is biologically very important. as it is a precursor from which prostaglandins and leukotrienes are synthesized in the body. Essential fatty acids are present in the structural lipids of the cell and are important constituents of mitochondrial lipids.

Linoleic acid is mainly present in plants and seed oils while arachidonic acid is of animal origin. However, high content of linoleic acid is seen in chicken fat and low content in coconut oil.

Non-essential fatty acids can be synthesized from products of glucose oxidation via pyruvate and do not, therefore, have to be included in the diet. Fatty acids are classified into two types:

(a) **Saturated fatty acids.** They do not have double bond in their carbon chains. General formula for saturated fatty acids is $C_nH_{2n}O_2$. Simplest of saturated fatty acids is Acetic acid. Other saturated fatty acids are— Palmitic acid ($C_{16}H_{32}O_2$), stearic acids ($C_{18}H_{36}O_2$), arachidic acid, ($C_{20}H_{40}O_2$), butyric acid etc.

CH_3——$(CH_2)_{14}$——COOH
Fatty acid
(Palmitic acid)

(b) **Unsaturated fatty acids.** These possess one or more double bonds in their carbon chains. Triple bonds occur rarely in fatty acids. General formula is $C_nH_{2n-2x}O_2$. Unsaturated fatty acids may further be classified as below;

1. **Monounsaturated.** Contain one double bond *e.g.*, Oleic acid ($C_{18}H_{34}O_2$).

2. **Polyunsaturated fatty acids.** They contain two or more double bonds *e.g.*, Linoleic acid (with two double bonds, $C_{18}H_{32}O_2$), linolenic acid (with three double bonds, $C_{18}H_{30}O_2$), and arachidonic acid (with four double bonds, $C_{20}H_{32}O_2$).

3. **Eicosanoids.** These compounds are derived from eicosa- (20-carbon) polyenoic fatty acids. They are further classified into

(a) Prostanoids:— (i) Prostaglandins (ii) Prostacyclins (iii) Thromboxanes;

(b) Leukotrienes

Most plant lipids have unsaturated fatty acids while most animal lipids have saturated fatty acids, **however, aquatic animals possess unsaturated fatty acid. Carboxylic group of fatty acids is polar,** water soluble or hydrophilic while rest of hydrocarbon chain is non polar, water insoluble or hydrophobic. Polar end of fatty acid sticks to water forming monomolecular layer over it. Polar end of fatty acid reduces surface tension and increases cleaning power of water.

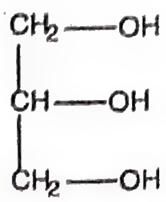
Classification of Lipids

1. **Simple lipids.** (i) Neutral fats (ii) Waxes—formed of fatty acids and alcohol. They do not have any additional group.

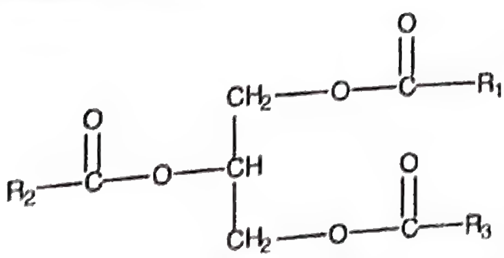
2. **Compound lipids.** (i) Phospholipids (ii) Glycolipids (iii) Lipoproteins—possess additional group besides fatty acids and alcohol.

3. **Derived lipids.** (i) Fatty acids (ii) Glycerol (Trihydroxy propane) (iii) Sterols—lipid like chemicals or derivatives of lipids.

(1) **Neutral fats or true fats.** They are triglycerides formed by esterification of three molecules of fatty acids with one molecule of trihydric alcohol glycerol. The word triglycerides refer to the number of 3 molecules of fatty acids esterified to a molecule of glycerol. Ester is called diglyceride if number of fatty acids is 2 and monoglyceride if number of fatty acids is one.



Glycerol



Triglyceride (R_1, R_2 and R_3 are fatty acids)

Depending upon the fatty acids present they are called tripalmitin, tristearin, palmito-oleio-stearin etc. All three fatty acids are only rarely similar *i.e.*, tripalmitin, they are called **pure fats or simple**

fats. Usually these fatty acids are dissimilar and fats are known as **mixed fats** *e.g.*, butter. Most natural fats are mixed fats.

Fats are differentiated into hard fats and oils. Oils are fats which are liquid at room temperature of 20°C because of their low melting point *e.g.*, groundnut oil, cotton seed oil, mustard oil, sesame oil, sunflower oil, safflower oil etc. **Oils are richer in either unsaturated fatty acids or fatty acids having small carbon chains.** Unsaturated fatty acids can combine with oxygen and other chemicals, thus exposed oils have a tendency to solidify. Hence also called drying oils. By hydrogenation unsaturated fatty acids are changed to saturated state. Edible oils can be converted into hard fats by this process. Vanaspati or vegetable ghee and margarine are obtained from oils through hydrogenation.

Oils with polyunsaturated fatty acids (called polyunsaturated) lowers blood cholesterol levels and hence are recommended to persons having hypertension, high blood cholesterol and other cardiovascular diseases. Edible oils having polyunsaturated fatty acids (PUFA) are safflower and sunflower oils.

Hard fats are solid at room temperature and they contain long chain of saturated fatty acids *e.g.*, animal fat.

Fats are a highly efficient form in which to store metabolic energy. This is because fats are less oxidised than are carbohydrates or proteins and hence yield more energy on oxidation. Furthermore, fats, being non-polar, are stored in anhydrous form, whereas glycogen, binds about twice its weight of water under physiological conditions. Fats, therefore, provide about six times the metabolic energy of an equal weight of hydrated glycogen.

(2) **Waxes.** They are fatty acid (saturated) esters of long chain monohydric alcohols like cytyl, ceryl or mericyl.

Plants waxes occur in cuticle and as grayish waxy coating or bloom around the plant organs. Wax found on the surface of land plants is useful in reducing transpiration.

In animals cutaneous glands secrete wax lanolin, which forms protective coating on animal fur.

Bee's wax is secreted by their abdominal glands. Bee wax is a complex of several waxes. The major component is ester of palmitic acid and mericyl alcohol (= triacontanol, $C_{30}H_{61}OH$). Second major component is ester of palmitic acid with hexacosonol ($C_{26}H_{53}OH$).

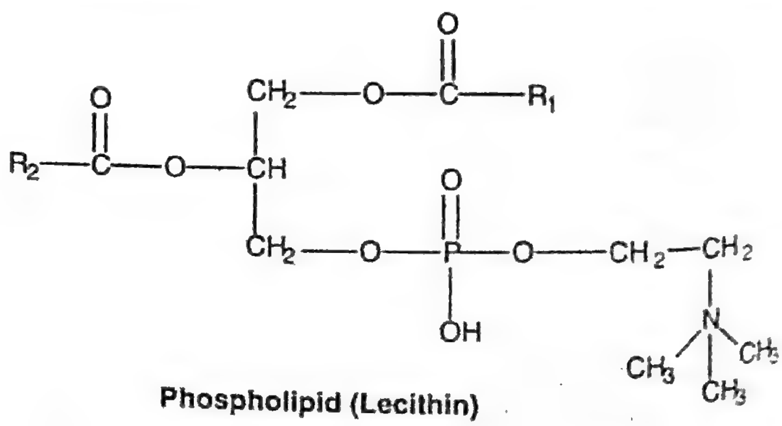
Paraffin wax is obtained from petroleum. Candles are made of paraffin wax and stearic acid.

Bacteria that cause tuberculosis and leprosy produce a wax (Wax-D) that contributes to their pathogenicity.

(3) **Cutin.** It is a complex lipid produced by cross esterification and polymerization of hydroxy fatty acids, and other fatty acids with or without esterification by alcohols other than glycerol. It occurs in the aerial epidermal cell walls and as separate layer of cuticle on the outside of these cells. Cuticle has 50-90% cutin. It reduces rate of transpiration and binds epidermal cells.

(4) **Suberin.** It is a mixture of fatty material having condensation products of glycerol and phellonic acid or its derivatives. Suberin occurs in the walls of cork cells and endodermal cells and makes cell wall strong and impermeable.

(5) **Phospholipids.** They are the compound lipids where one fatty acid is replaced



Phospholipid (Lecithin)

by phosphoric acid linked to additional nitrogenous groups like choline (in lecithin), ethanolamine (in cephalin), serine or inositol.

Phospholipids are amphipathic carrying both hydrophilic polar and hydrophobic non-polar groups. Hydrocarbon chains of two fatty acids function as hydrophobic non-polar tails of the phospholipid molecules while phosphate and additional group behave as hydrophilic polar head of phospholipid. Phospholipid molecules arrange themselves to form a bilayer or double layer where polar heads of molecules form two surfaces, which are in contact with water while hydrophobic non-polar tails of phospholipids are towards the centre of the bilayer. Lipid bilayer is the basic component of all cell membranes.

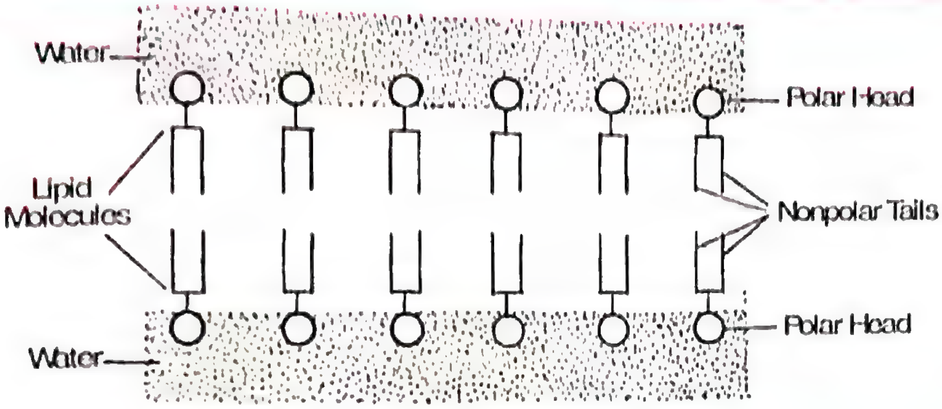


Fig. 9.1. Lipid bilayer.

Phospholipids are present in abundance in brain and nerve tissues. They also form important intermediate substances in the transport of lipids from and to the liver.

(6) **Sphingolipids.** They are lipids having amino alcohol sphingosine. Sphingomyelins are sphingolipids with an additional phosphate attached to choline like in phospholipids. It occurs in myelin sheath of nerves. Cerebrosides possess galactose as sugar residue. They occur in nerve membranes.

Gangliosides possess glucose, galactose, sialic acid and acetyl glucosamine. They function as viral receptors and also influence ion transport through the membrane. They occur in grey matter of brain and their excessive accumulation may lead to disorders *e.g.*, Tay-Sachs disease. As cerebrosides and gangliosides contain sugar residues they are also called glycolipids.

(7) **Lipoproteins.** They are composed of lipids and proteins and are present in blood, milk and egg yolk. Four major groups of lipoproteins which are important physiologically, include:

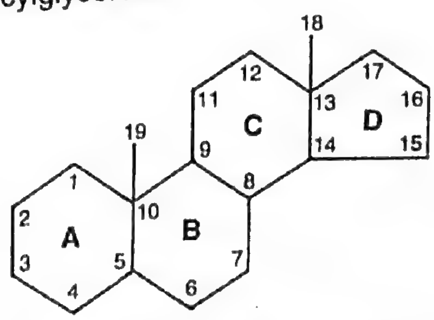
(i) **Chylomicrons.** Derived from intestinal absorption of triacylglycerols.

(ii) **Very low-density lipoproteins** (VLDL). Derived from liver for export of triacylglycerol.

(iii) **Low density lipoproteins** (LDL). Derived from VLDL.

(iv) **High-density lipoprotein.** It transports cholesterol from tissues to liver.

(8) **Steroids.** Steroids are a group of lipids, which possess a hydrogenated cyclopentanoperhydrophenanthrene ring system with numbered carbon atoms. To carbon atom number 10 and 13, methyl groups are attached having 19 and 18 carbon atoms respectively.



Cyclopentanoperhydrophenanthrene ring system.

Major groups of steroids are :—

(i) **Sterols.** They are the steroids with one or more —OH groups and no carbonyl or carboxyl group. Most important sterol in human body is cholesterol. The cell membrane of fungi contains a sterol called ergosterol.

Cholesterol. ($C_{27}H_{45}OH$) is the common sterol present in many animals, human beings and some plants. Structurally it has—

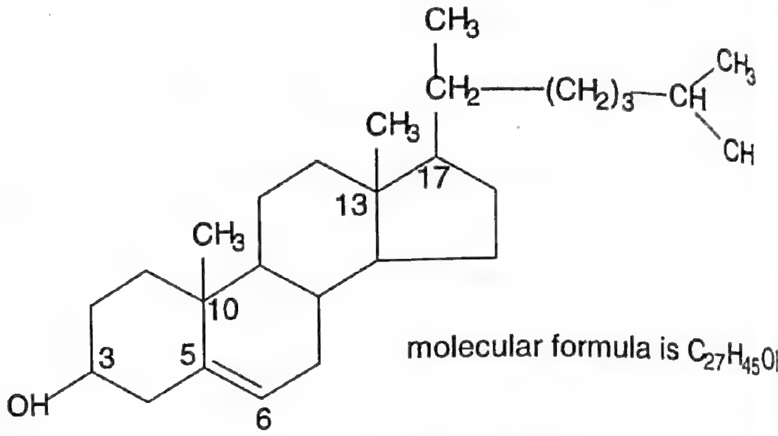
(a) Cyclopentanoperhydrophenanthrene ring

(b) An —OH group at C_3.

(c) Double bond between C_5 and C_6.

(d) Two —CH_3 groups at C_{10} and C_{13}.

(e) An eight carbon chain attached to C_{17}.



Cholesterol

It is manufactured inside the body in liver as well as supplied from outside. It occurs both in free and combined form when it is esterified with a fatty acid. Ester form of cholesterol is also known as bound form. Cholesterol and its esters are insoluble in water so when cholesterol level rises in blood it tends to get deposited in walls of arteries known as atherosclerosis, which leads to high blood pressure and many heart diseases. Important roles of cholesterol are— (a) It is a precursor of steroid hormones *e.g.*, progesterone, estradiol (female sex hormones), testosterone (male sex hormone), aldosterone, cortisol. (b) Relatively high content of cholesterol in skin causes vit. D formation by UV rays. (c) Cholesterol is present in blood and bile thus usually a major constituent of gallstones. (d) It is useful in fatty acid absorption. (e) It is essential for plant growth, induction of flowering and expression of sex in certain plants. (f) Cholesterol is a constituent of animal cell membrane and mycoplasma cell membrane. (g) Cholesterol helps in forming bile salts.

(ii) **Bile acids.** They are steroid carboxylic acids derived from cholesterol *e.g.*, glycocholic acid, taurocholic acid. These bile acids combine with sodium to form bile salts which have a remarkable ability to lower the surface tension and thus help in emulsification of fats.

(iii) **Anabolic steroids.** They are synthetic derivatives of testosterone which are used clinically in promoting growth and repair of body tissues in senile and debilitating illness.

Terpenes

They are lipid like hydrocarbons formed of isoprene (C_5H_8) units. Steroids like cholesterol are derived from terpenes having 6 isoprene units. Essential oils of plant origin are terpenes, *e.g.*, camphor, menthol. Gibberellins possess four isoprene units. An equal number of isoprene units occur in vitamin A, E and K. Phytol or tail of chlorophyll *a* molecule is a terpene with 4 isoprene units. Carotenoids have 8 isoprene units. Natural and synthetic rubbers are terpenes with thousands of isoprene units.

Functions of lipids

1. Fats serve as food reserve in both plants and animals.

2. Fats function as concentrated food because they yield more than twice as much energy per unit weight as compared to carbohydrates (9.3 K cal/gm: 4.5 kcal/gm.)

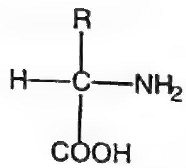
3. Fats can be converted to carbohydrates and thus fats stored in oil seeds *e.g.*, Groundnut, mustard, castor, cotton etc. not only provide energy but also raw material for growth of embryo.

4. Lipids stored in seeds and spores help in thermal insulation, protection from ultraviolet radiations and loss of water.

5. Adipocytes are fat containing cells which have higher amount of unsaturated fatty acids in cold blooded or poikilothermic animals as compared to warm blooded animals.
6. Fatty or adipose tissue forms an insulating layer below the skin of animals for protection against low temperature. Whales have a very thick layer of subcutaneous fat called **blubber.**
7. Subcutaneous fat rounds off the body contours of animals and human beings.
8. Plant fats are now days used for soap manufacturing.
9. Fragrance of many plant products is due to fat like substances called terpenes.
10. Prostaglandins are important hormones modulators.
11. Drying oils having unsaturated fatty acids are used in paint industry.
12. Desert animals employ fat as source of metabolic water *e.g.*, Camel uses fat stored in its hump for obtaining metabolic water during extreme desiccating conditions.

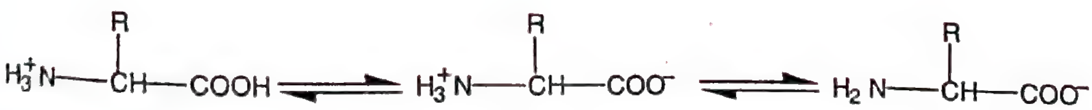
AMINO ACIDS

Amino acids are organic acids (with carboxylic group – COOH) having amino group ($-NH_2$) generally attached to α-carbon or carbon next to the carboxylic group (**and hence also called α–amino acids**). Carboxylic group provides an acidic group to the amino acids while amino group gives it a basic reaction. The α-carbon also bears a variable hydrocarbon or alkyl group R and hydrogen.



Here R stands for H or other groups. The carbon holding the amino group is asymmetric. R may be a straight or branched hydrocarbon chain or a cyclic group. Hydrocarbon may be polar (*e.g.*, in serine, glutamate or glutamic acid) or nonpolar (*e.g.*, in alanine). In heterocyclic amino acids *viz.* proline and hydroxyproline, amino group ($-NH_2$) is replaced by imino group (>NH) which also represents tail of R-group. Except in glycine (where R is represented by H), α-carbon is asymmetric.

A particular property of amino acids is the ionizable nature of $-NH_2$ and $-COOH$ groups. Hence in solutions of different pHs, the structure of amino acids changes.



(A) (B) (C)

B is called zwitterionic form.

In proteins, twenty types of amino acids and amides occur which are called **protein amino acids.** Incorporation of these amino acids is controlled by triplet codes of DNA/mRNA. A protein may also possess noncoded amino acids, which are called **rare amino acids**. These amino acids are derived from modifications of coded amino acids *e.g.*, hydroxyproline from proline and hydroxylysine from lysine. First three letters of amino acid names are used as abbrebiations for amino acids e.g. Ala for alanine, Gly for glycine etc.

Non protein amino acids do not occur in proteins. These amino acids take part in important biosynthetic pathyways *e.g.*, ornithine and citrulline are involved in urea cycle. Homo arginine and diaminobutyric acid are a source of nitrogen. Gamma aminobutyric acid (GABA) acts as an inhibitory neurotransmitter in brain. Diaminopimelic acid is an intermediate of lysine synthesis. Rare amino acids and non-proteins amino acids are included under non-standard amino acids.

Nutritionally amino acids are of two types :—

(a) **Essential amino acids.** Plants can synthesise all the protein amino acids required by them. Animals cannot manufacture their amino acids and they depend upon the plants directly or indirectly for that. Some of these amino acids can be synthesized by animals through transformation and transamination. The amino acids which cannot be synthesized by animals through transformation or transamination are called essential amino acids. These amino acids are —

1. Leucine	2. Isoleucine	3. Valine	4. Tryptophan
5. Phenylalanine	6. Lysine	7. Methionine	8. Threonine

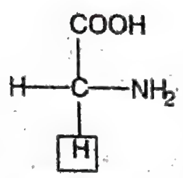
These amino acids must be present in the diet.

(b) **Non-essential amino acids.** These amino acids can be synthesized by body and, therefore, are not required to be components of diet.

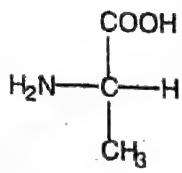
Semi essential amino acids. They are growth promoting factors. Since they are not synthesized in sufficient quantity during growth, they become essential in growing children, pregnancy and lactating women. They include argenine and histidine.

Depending upon structure and reaction amino acids are differentiated into following types:

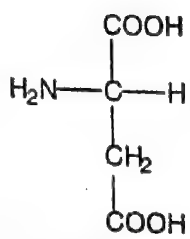
Type	Amino Acids
1. Neutral (amino acids with one carboxylic and one amino group and non cyclic hydrocarbon chain)	Glycine (Gly), Alanine (Ala), Valine (val), Leucine (Leu), Isoleucine (Ile)
2. Acidic (Amino acids having one extra carboxylic group)	Aspartic acid (Asp), Asparagine (amide, Asn), Glutamic acid (Glu), Glutamine (Gln)
3. Basic (amino acids with an additional amino group without forming amides)	Arginine (Arg), Lysine (Lys), Histidine (His)
4. Sulphur containing (these amino acids posses sulphur)	Cysteine (Cys), Methionine (Met), Cystine (containing two cysteine units)
5. Alcoholic (amino acids having alcoholic or hydroxyl group)	Serine (Ser), Threonine (Thr), Tyrosine
6. Aromatic (they possess cyclic structure with a straight side chain bearing carboxylic and amino groups).	Phenylalanine (Phe), Tyrosine (Tyr), Tryptophan (Try), Histidine
7. Heterocyclic (they have a nitrogen in ring structure)	Histidine (His), Proline (Pro)



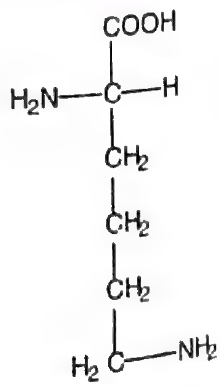
Glycine



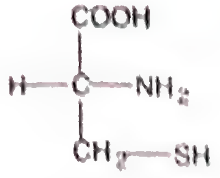
Alanine (Neutral)



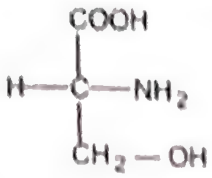
Aspartic acid (acidic)



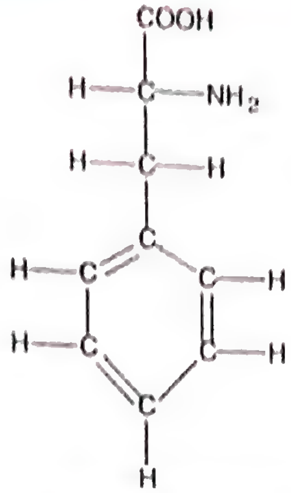
Lysine (Basic)



Cysteine (Sulphur containing)



Serine



Phenylalanine (Aromatic)

- **Ninhydrin test is used for detection of amino acids.**

Amino acids with non-polar side chains.

1.	Glycine	Gly	G
2.	Alanine	Ala	A
3.	Valine	Val	V
4.	Leucine	Leu	L
5.	Isoleucine	ILe	I
6.	Methionine	Met	M
7.	Proline	Pro	P
8.	Phenyl alanine	Phe	F
9.	Tryptophan	Trp	W

Amino acids with uncharged polar side chains.

10.	Serine	Ser	S
11.	Threonine	Thr	T
12.	Asparagine	Asn	N
13.	Glutamine	Gln	Q
14.	Tyrosine	Tyr	Y
15.	Cysteine	Cys	C

Amino acids with charged polar side chains.

16.	Lysine	Lys	K
17.	Arginine	Arg	R
18.	Histidine	His	H
19.	Aspartic Acid	Asp	D
20.	Glutamic Acid	Glu	E

- For undetermined / nonstandard amino acid the one letter symbol is X.

Peptide Formation

Peptide refers to a molecule composed of a short chain of amino acids such as dipeptide (2 amino acids), tripeptide (3 amino acids) etc. A covalent bond called peptide bond forms between amino group of one amino acid and carboxyl group of another amino acid. This bonding results in production of molecules varying in length from two amino acids to chains containing thousands of amino acids. This reaction results in elimination of molecules of water. Peptide thus formed has a

carboxylic group at one end and amino group at other end. A polypeptide contains unspecified number of amino acids (usually more than 20) and it is often a smaller subunit of a protein. A polypeptide with molecular weight > 10,000 is called protein.

Functions of amino acids

1. They are the building blocks of proteins and enzymes.

2. Specific amino acids give rise to specialized products responsible for important physiological functions *e.g.*, (i) Tyrosine forms hormones *e.g.*, thyroxine, epinephrine and melanin (a pigment). (ii) Tryptophan synthesizes a vitamin, niacin and plant hormone indole-3-acetic acid or IAA. (iii) Histidine decarboxylation forms histamine required for optimum functioning of muscles, blood capillaries and gastric secretions. (iv) Glycine is used for synthesis of heme and protoporphyrin. (v) Coenzyme glutathione is formed by glycine, glutamate and cysteine.

3. Methionine acts as donor of methyl groups in synthesis of various organic compounds.

4. Cysteine and methionine are sources of sulphur.

5. Ornithine and citrulline are components of urea cycle.

6. Encephalins are small peptides produced by nerve cells, which function as body opiate influencing perception of pleasure and pain.

7. Many non protein amino acids are components of antibiotics.

8. Small peptides are associated with structural units of prokaryotic walls called peptidoglycans.

9. Excess amino acids are deaminated in liver while organic acid is changed to glucose (gluconeogenesis or used directly in metabolism).

10. Diaminopimelic acid, an intermediate of lysine synthesis, is a component of prokaryotic cell wall.

11. β-alanine plays role in synthesis of coenzyme A and pantothenic acid (a vitamin).

PROTEINS

Proteins are large sized molecules or macromolecules having one or more polypeptides. They are the most abundant and most varied of macromolecules of cells which constitute about 50% of their dry weight. Each cell type has some unique proteins. Proteins of closely related species may be similar.

Being macromolecules proteins are not freely soluble in water but may form colloidal complex with the same. Chemically protein is composed of carbon, hydrogen, nitrogen, oxygen and sulphur. Minimum molecular weight among proteins is of adrenocorticotropin hormone (4500), insulin (5733 for bovine insulin) and bacterial ferredoxin (6000).

Number of polypeptides in a protein may vary from one to many. A protein having one polypeptide is a **monomeric protein,** *e.g.*, myoglobin, ribonuclease. A protein with two or more polypeptides is called **oligomeric protein** (some call it multimeric) *e.g.*, insulin with two polypeptides, ribulose biphosphate carboxylase having 24 polypeptides and pyruvate dehydrogenase complex having 72 polypeptide.

A polypeptide contains from a few to few hundred amino acid residues. These amino acids are linked serially by peptide bonds. The sequence of amino acids in a polypeptide is specific for a particular protein. The distinctive sequence of amino acid units is governed by the codon sequence of gene or cistron controlling its formation. 20 protein amino acids are used in the synthesis of all types of proteins. In a polypeptide of only 100 amino acid residues, there is possibility of 20^{100} arrangements or types of polypeptides thus accounting for thousands of specific proteins found in living species. Proteins having all the essential amino acids are called **first class proteins.**

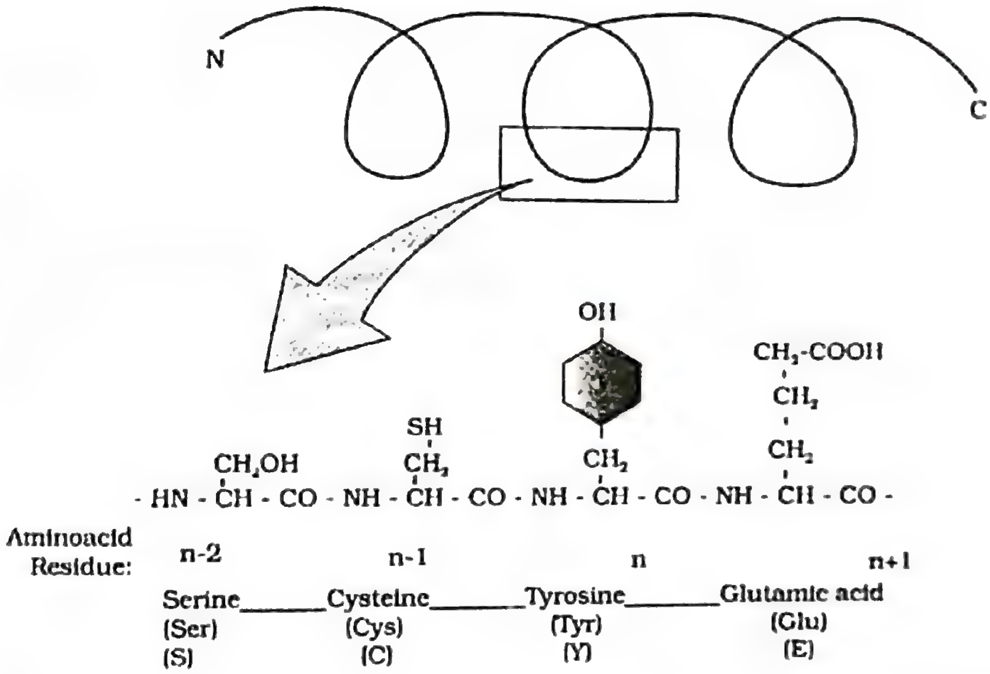
Collagen is the most abundant protein in animal world and Ribulose bisphosphate Carboxylase – Oxygenase (RUBISCO) is the most abundant protein in the whole of the biosphere.

Structure of proteins

A protein can have upto four levels of organization.

(A) **Primary structure.** The linear sequence of amino acids in a polypeptide chain is the primary structure of the protein. It describes number of polypeptides, number and sequence of amino acids in polypeptide. The first protein to have its primary structure determined was insulin.

The first amino acid is also called as N-terminal amino acid. The last amino acid is called the C-terminal amino acid.



Primary structure of a portion of a hypothetical protein. N and C refer to the two termini of every protein. Single letter codes and three letter abbreviations for amino acids are also indicated.

Specific amino acids in primary structure determine the places where polypeptides are to bend or fold and where different lengths will be attracted to each other. Distance between two adjacent peptide bonds is about 0.35 nm.

(B) **Secondary structure.** Development of stearic relationship between amino acids of linear polypeptide sequence results in 3 dimensional secondary structures by folding or coiling. The linkage or bonds involved in secondary structure formation are hydrogen bonds and disulphide bonds. There are 3 types of secondary structures *viz.*, α-helix, β-pleated and collagen helix. α and β designate the first and second secondary structure discovered in proteins.

1. **α-helix (Fig. 9.2).** In this the polypeptide chain is coiled spirally, in right-handed manner. The helix is stabilized by hydrogen bonds between oxygen of carboxylic group of one amino acid residue and >NH group of next fourth amino acid residue. At places helix is less regular forming random coils. This secondary structure is found in various proteins *e.g.*, α – keratin, myosin, tropomysin, epidermin and fibrin. In α–helix, there are 3.6 residues per turn and the pitch is 5.4 Å (pitch is the distance, the helix rises along its axis per turn).

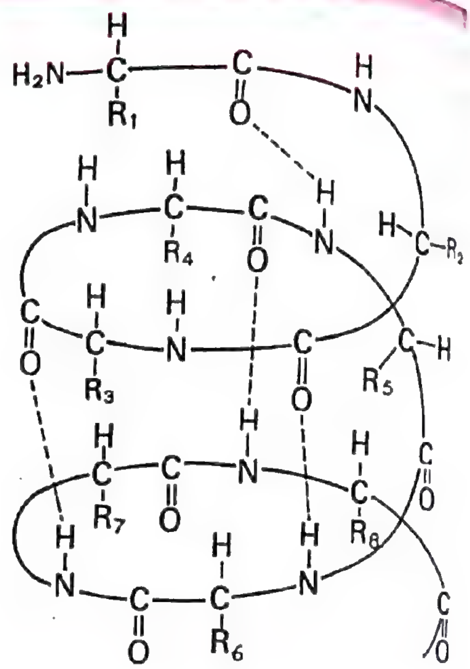


Fig. 9.2. α - Helix

2. **β-pleated.** In this two or more polypeptide chains get interconnected by hydrogen bonds resulting in formation of a sheet. Adjacent strands of polypeptides may run in same direction (parallel β - sheet *e.g.*, β - keratin) or in opposite direction (antiparallel β-sheet *e.g.*, fibroin of silk). The structure is not absolutely planar but is slightly pleated due to angles of bonds. In some cases single polypeptide may show α-helix in some portions and bent to form two or more parallel strands with β -pleated structure in other parts *e.g.*, ribonuclease.

3. **Collagen Helix.** In this there are three strands or polypeptides coiled around one another, strengthened by hydrogen bonds between >NH group of glycine residue of each strand with –CO group of other two strands. Collagen forms largest part of the fibres and is a component of most connective tissues. About 30% of all proteins in body is collagen. It contains a large preponderance of 3 amino acids-glycine, proline and hydroxyproline. Every third amino acid in polypeptide chain is glycine and every fifth amino acid is proline or hydroxyproline. Presence of ring structures of proline and hydroxyproline make it difficult for true alpha helical structure to be formed. Thus polypeptides show a general left handed turn in such a way as to bring short glycine residues on to one surface and ring structures to another. Three such polypeptide chains are twisted right handedly to form a compact rope-like structure by bringing glycine bearing surfaces together.

(C) **Tertiary structure.** In this the complex secondary structure takes a three dimensional shape in which there is folding, looping and binding of chains including all its secondary features *e.g.*, helix, sheets etc. This is carried out in such a way that active sites (polar groups) of proteins are exposed to the surface while most non polar groups are brought to the interior of the protein. Final shape may be an ellipsoide, a globe or any irregular shape and it is determined by intermolecular forces and bonds in the polypeptide chains. These forces are hydrogen bonds, electrostatic bonds, ionic bonds, covalent bonds and hydrophobic bonds. These bonds can be broken by high energy radiation, high temperature, drastic changes in *p*H and salts of heavy metals. This degradation of tertiary structure is known as **denaturation**. In some cases removal of denaturing agent re-establishes bonds required for tertiary structure, this is called **renaturation**. Proteins can also be coagulated or precipitated by low temperature and various chemicals.

Covalent bonds in protein structure are the strongest bonds. They are of two types *viz.*, –S–S- (disulphide) bonds and peptide bonds. **Ionic bonds** occur due to attractive forces between oppositely charged –NH_3^+ and –COO^- groups. **Hydrogen bonds** develop by sharing of H^+ by two electronegative atoms. **Hydrophobic bond** forms between two non-polar groups and it helps in excluding H_2O in that area thus increasing compaction.

Tertiary structure is absolutely necessary for the many biological activities of proteins.

(D) **Quarternary structure.** In this each polypeptide develops its own tertiary structure and functions as protein subunit. The different subunit chains pack together to give quarternary conformation *e.g.*, haemoglobin.

Reaction with Proteins

In aqueous medium a protein possess both cationic and anionic group thus called amphoteric.

(A chemical carrying both positive and negative charges is called amphoteric). **At a specific pH, *i.e.*, isoelectric point, a protein may be electrically neutral as number of positive charges are exactly balanced by the number of negative charges.**

At physiological *p*H a protein having more positive charges is called **basic protein**. These proteins are rich in basic amino acids *e.g.*, lysine and arginine. Histones associated with DNA are basic proteins. Proteins with more negative charges are **acidic proteins** and they possess acidic amino acids *e.g.*, aspartic acid and glutamic acid. Most blood proteins are acid proteins. **Neutral proteins** have their isoelectric point at 7.4 *p*H.

Properties

1. **Variety.** There are thousands of proteins present in each organism.

2. **Specificity.** Each species has certain specific proteins not found in others. Closely related species share several common proteins. Number of common proteins decreases with the increase in dissimilarity between species.

3. **Large-Sized Molecules.**

4. **Colloids.** Being large-sized, many proteins function as colloids and form colloidal solution.

5. **Reactivity.** A protein molecule can hold a number of substances over its surface and react with many chemicals due to the presence of several reactive groups on its amino acids.

6. **Permeation.** Cell membranes do not allow permeation to proteins. They pass outwardly and inwardly through exocytosis and endocytosis. Normally, every cell synthesizes its own proteins from amino acids.

7. **Amphoteric Nature.**

8. **Denaturation.** Bonds maintaining structure of proteins are easily broken by high temperature and high energy radiations.

Classification of Proteins

(A) On the Basis of Shape

I. **Fibrous proteins.** They are thread like proteins which may occur singly or in groups. They generally possess secondary structure and are tough, non enzymatic structural proteins. These proteins are insoluble in water. Keratin of hair and skin is a fibrous protein. Myosin of muscles and elastin of connective tissue are fibrous as well as contractile proteins.

II. **Globular protein.** They are rounded non-contractile proteins having a tertiary or quarternary final structure. Smaller globular proteins are soluble in water. They are not coagulated by heat. Increase in size of globular proteins increases coagulability but decreases solubility. Globular proteins may or may not be enzymatic. Examples of large globular proteins are egg albumin, serum globulin and glutelins.

(B) On the Basis of Function. Functionally proteins are classified into enzymatic and non-enzymatic types.

I. **Enzymatic proteins.** They are proteins which act as enzymes, either directly *e.g.*, amylase or in conjuction with a non protein cofactor *e.g.*, dehydrogenases. These are usually globular proteins.

II. **Non-enzymatic proteins.** These can be of further following types—

(i) **Structural or protoplasmic proteins.** These form part of cellular structures *e.g.*, colloidal complex of protoplasm, cell membranes, contractile proteins, structural proteins of hairs and nails. These proteins can be globular or fibrous in shape.

(ii) **Reserve or storage proteins.** These occur as food reserve mostly in seeds, eggs or milk. They are usually globular. They are of 4 types depending upon their solubility— Albumins, globulins, protamines and glutelins.

(iii) **Defence proteins.** Immunoglobulins involved in defence mechanisms.

(iv) **Hormonal proteins**

(v) **Respiratory proteins.** Involved in function of respiration, *e.g.*, hemoglobin, myoglobin etc.

(C) On the Basis of Constitution

I. **Simple proteins.** They are proteins made up of amino acids only. Additional non amino groups are absent *e.g.*, histones.

II. **Conjugated proteins.** These proteins in addition to amino acids contain a non protein, prosthetic groups in their structure. Depending upon the prosthetic group they are of following types—

Conjugated protein	Prosthetic group	Occurrence
1. Nucleoproteins		
- Deoxyribonucleoprotein	DNA	Chromosome
- Ribonucleoprotein	RNA	Ribosome
2. Chromoproteins		
(i) Haemoglobin	Fe	Erythrocytes
(ii) Cytochromes	Fe	Enzymes, electron carriers
(iii) Haemocyanin	Cu	Blood of some animals
(iv) Chloroplastins	Chlorophylls	Thylakoids
3. Metalloproteins	Zn, Cu, Mn, Fe	Iron in ferritin
4. Glycoproteins	Carbohydrates	Plasma membrane, cell wall
5. Mucoproteins	Mucoid carbohydrates	Mucin
6. Lipoproteins	Lipids	Cell membranes
7. Phosphoproteins	Phosphate	Casein (milk)

III. **Derived proteins.** These are the proteins formed from native proteins by the action of heat, physical forces or chemical forces *e.g.*, metaprotein, proteoses, fibrin and peptides etc.

Functions of proteins

1. Fibrous proteins like keratin forms external protective structures of animals *e.g.*, nails, hoofs, scales, hairs etc. Silk worms protect themselves in cocoon stage by silk fibres, which are made up of protein fibroin. Spider webs are also made up of this protein.

2. Many proteins form supporting structures *e.g.*, elastin of ligaments, collagen of tendons, bone, cartilage and connective tissue.

3. Actin and myosin are fibrous proteins forming the contractile system of muscles.

4. Microtubules are hollow, unbranched tubules forming structural material of cilia, flagella, basal bodies and spindle apparatus. These microtubules are built up of protofilaments formed of α and β tubulins.

5. Haemoglobin of RBCs transports oxygen from lungs to different parts of body thus functioning as transport or carrier protein.

6. α-globulin carries thyroxine and bilirubin. β-globulin transports vitamins A, D and K, cholesterol and ions while albumin transports calcium and fatty acids.

7. Proteins on external surface of cell membranes act as cell receptors. The proteins bind to specific information molecules *e.g.*, hormones and mediate its cellular effects.

8. Proteins help in keeping *p*H constant. Polar chains of proteins can combine with excess acid and base.

9. Some hormones are proteinaceous *e.g.*, insulin, growth hormone of pituitary, parathyroid hormone, all of which carry important roles.

10. Gene repressors which regulate gene action are proteinaceous in nature.

11. Monellin is the sweetest chemical, obtained from an African berry. It is actually a protein and is a boon for diabetic patients as it is nonfattening, non caloric and non toxic sweetener. It is 2000 times as sweet as sucrose.

12. Blood clotting proteins viz. fibrinogen and thrombin prevent blood loss from injured vessels by clotting the blood.

13. Rhodopsin and iodopsin, the protein pigments present in rods and cones of retina, take part in perception of image.

14. Mucoproteins form mucus which protects lining layer of alimentary canal from friction and digestive juices.

15. Proteins being multivalent macromolecules can carry on a number of chemical reactions.

16. Human memory is believed to be stored in specific proteins called memory proteins.

17. Myoglobin of muscles stores oxygen.

18. Except for RNA enzymes, all enzymes are made up of proteins.

19. P-protein which is present in sieve tube elements, play role in transport of nutrients.

20. Toxins produced by certain animals, plants and bacteria are made up of proteins. These toxins act as both defensive and offensive proteins.

21. Antibodies (Immunoglobulins) are proteins produced by lymphocytes.

22. Pollen grains possess proteins for compatibility – incompatibility reaction with stigma during pollination.

23. Milk, eggs and seeds contain storage proteins for nourishment of the young ones. Milk contains a protein called **casein**. Egg white contains **ovalbumin** and cereals contain **glutelin.** Ferritin is an iron storing protein commonly found in animal tissues.

24. GLUT-4 enables glucose transport into cells.

NUCLEOTIDES

The basic unit of nucleic acids is nucleotides. They also act as coenzymes, are part of energy carriers and some may function as chemical messengers.

Nucleotide = Nitrogen base + Pentose sugar + Phosphoric acid

The two types of pentose sugars in nucleotides are – ribose ($C_5H_{10}O_5$) and deoxyribose ($C_5H_{10}O_4$), which occur in â-furanose state or pentagon ring with one oxygen and four carbon atoms. The fifth carbon having – CH_2OH complement lies outside the ring. Carbon atom 2 contains two hydrogen atoms in deoxyribose whereas in ribose it has a hydroxyl (-OH) group instead of a second hydrogen. Deoxyribose occurs only in those nucleotides which make up the hereditary material DNA. Ribose is found in nucleotides forming RNA and a number of other compounds like AMP, ATP, NAD, NADP, FAD, CoA, etc.

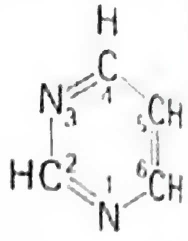
Nitrogen bases are of two types, **purines** and **pyrimidines** and are heterocyclic compounds. They do not have OH group, but are still called bases as they have negatively charged N and O which can accept positively charged atoms, *i.e.*, they act as hydrogen-ion acceptors.

As per IUB nomenclature, unspecified purines are abbreviated as R and unspecified pyrimidines as Y.

Pyrimidine Bases

They are 6 membered rings with nitrogen at 1 and 3 positions. Pyrimidine bases found in nucleic acids are mainly of three types: -

- Cytosine found in both DNA and RNA
- Thymine found in DNA only.
- Uracil found in RNA only.



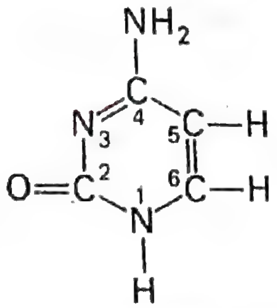
Pyrimidine

The pyrimidine nucleus is as below :

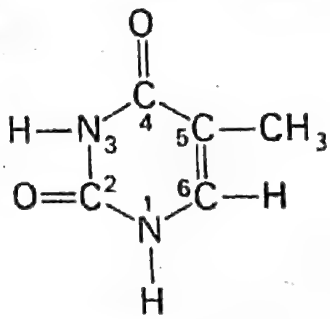
(i) Cytosine: Cytosine is chemically **2-oxy-4-amino pyrimidine.**

(ii) Thymine (5-methyl uracil): Chemically it is **2, 4 – dioxy 5-methyl pyrimidine**

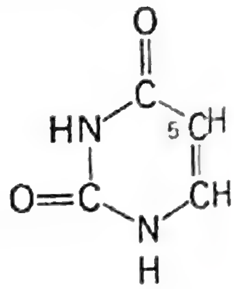
(iii) Uracil – Chemically it is **2, 4 – dioxy pyrimidine.**



Cytosine

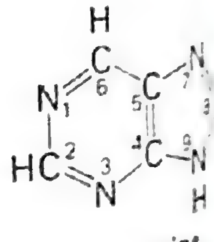


Thymine



Uracil

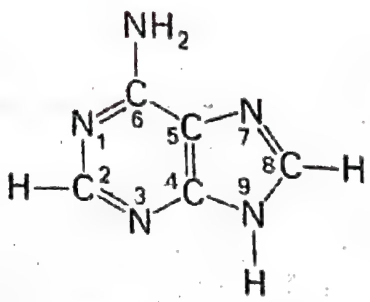
Purine Bases. The purine ring is more complex than pyrimidine ring. It is considered the product of fusion of a pyrimidine ring with an imidazole ring at the 4 and 5 positions thus forming a 9 membered double ring structure. It has nitrogens at 1, 3, 7 and 9 positions. The purines are of two types — (i) Adenine (ii) Guanine.



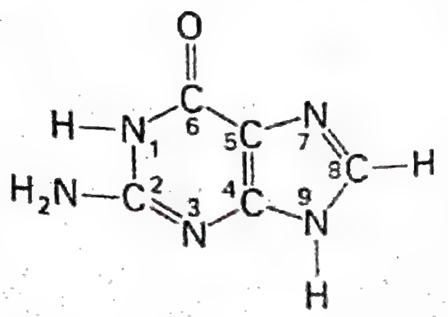
Purine

(i) Adenine: Chemically it is **6-amino-purine.**

(ii) Guanine: Chemically it is **2-amino-6-oxy purine.**



Adenine (6-aminopurine)



Guanine

Free pyrimidines and purines are weakly basic compounds, thus are called bases. Nucleic acids absorb UV light at wavelengths near 260nm. The purines and pyrimidines are hydrophobic and relatively insoluble in water at the near neutral *p*H of the cell.

Nucleoside (Nitrogen Base + Pentose Sugar)

The nitrogen base combines with the sugar molecule at its carbon atom 1' in a β-N glycosidic linkage (C-N-C) by one of its nitrogen atoms (usually 1 in pyrimidines and 9 in purines). Depending upon the type of pentose sugar, nucleosides are differentiated into **ribonucleosides** and **deoxyribonucleosides.**

- Uracil produces nucleoside with only ribose sugars.
- Thymine similarly forms nucleoside with only deoxyribose sugar.
- Other nitrogen bases produce nucleosides with both ribose and deoxyribose sugars.
- The various nucleosides are – **Adenosine** (adenine + ribose), **Deoxyadenosine** (adenine + deoxyribose), **Guanosine** (guanine + ribose), **Deoxyguanosine** (guanine + deoxyribose), **Uridine** (uracil + ribose), **Deoxythymidine** (thymine + deoxyribose), **Cytidine** (cytosine + ribose), **Deoxycytidine** (cytosine + deoxyribose)

Nucleotides are phosphoric acid esters of nucleosides and therefore also called nucleoside phosphates. Phosphate attaches to the sugar molecule at its 5' carbon atom but rarely may link to 3' carbon atom or to 2' carbon atom also. **The bond between the phosphate and hydroxyl group of sugar is an ester bond. As there is one such ester bond on either side, it is called phosphodiester bond.** The number of phosphoric or phosphate residues may be upto three in free occurring nucleotides. Nucleotides may be ribonucleotides (= ribotides) or deoxyribo-nucleotides (= deoxyribotides) depending on the pentose sugar present. The various nucleotides are adenylic acid (adenosine monophosphate or AMP), deoxyadenylic acid (dAMP), guanylic acid (guanosine monophosphate or GMP), deoxyguanylic acid (dGMP), uridylic acid (uridine monophosphate or UMP), deoxythymidylic acid (deoxythymidine monophosphate or dTMP), cytidylic acid (cytidine monophosphate or CMP) and deoxycytidylic acid (dCMP).

Higher Nucleotides

Nucleotides having more than one phosphate group are called **higher nucleotides** and they occur in the free state. They have high-energy bonds between the 2nd and 3rd phosphates and so these function as energy carriers.

Classification

A. **Adenosine nucleotides.** ATP, ADP, AMP and Cyclic AMP.

B. **Guanosine nucleotides.** GTP, GDP, GMP and Cyclic GMP.

C. **Uridine nucleotides.** UTP, UDP, UMP, UDP-G.

D. **Cytidine nucleotides.** CTP, CDP, CMP and certain deoxy CDP derivatives of glucose, choline, ethanolamine.

Functions of Nucleotides

1. They are **building blocks** of nucleic acids, ribonucleotides for RNAs while deoxyribonucleotides produce DNA.
2. Cyclic AMP (cAMP) is the mediator of hormone action by acting as a second messenger.
3. Cyclic GMP (cGMP) is functional in Ca^{2+} or Calmodulin mediated chemical reaction.
4. Higher nucleotides behave as **energy carriers.** ATP is known as energy currency of the cell.
5. Nucleotides produced by nicotinamide and riboflavin function as **coenzymes** (NAD^+, $NADP^+$, FMN and FAD) of dehydrogenases or oxidases.

6. CoA from pantothenic acid functions as Acyl group carrier.

7. UDP and ADP are involved in synthesis of polysaccharides while CDP and CTP are required in phospholipid synthesis.

Discovery of DNA

History

- Nucleic acids first isolated by Friedrich Miescher from pus cells. **He named it as Nuclein.**
- Name Nucleic acid was given by Altmann.
- Presence of purine and pyrimidine bases in nucleic acids discovered by Fisher.
- Levene found that deoxyribose nucleic acid contains phosphoric acid and deoxyribose sugar. He characterised four types of nucleotides.
- Chargaff – Found that purines = pyrimidine in DNA and also adenine = thymine; guanine = cytosine.
- Astbury – Found by x-ray diffraction that DNA has many nucleotides which are arranged perpendicular to the long axis of the molecule and separated from each other by 0.34nm.
- In 1953, Wilkins and Franklin got very fine X-ray photographs of DNA. The photographs showed that DNA is a helix with a width of 2nm. One turn of helix was 3.4nm with 10 layers of bases stacked in it.
- Watson and Crick received Nobel Prize of Medicine and Physiology (1962) for building a double helix model of DNA. Watson and Crick based their model on the X-ray diffraction data produced by Maurice Wilkins and Rosalind Franklin. They published their data in the American journal "The Nature" on the basis of their work on *E. coli.*
- *In vitro* synthesis of DNA – Korenberg (1959).

Important features of Watson and Crick double helical model of DNA

1. The double helix comprises of two polynucleotide chains.
2. The two strands (polynucleotide chains) of double helix are antiparallel.
3. Each polynucleotide chain has a sugar-phosphate 'backbone' with nitrogenous bases directed inside the helix and the sugar phosphate on the outside. These bases are stacked in a pile on top of each other.
4. The nitrogenous bases of two antiparallel polynucleotide strands are linked through hydrogen bonds. There are two hydrogen bonds between A and T, and three between G and C. The hydrogen bonds are the attractive forces between the two polynucleotides of double helix and serve to hold the structure together. ***The plane of one base pair stacks over the other in double helix. This, in addition to H-bonds, confers stability to the helical structure.***
5. The two polynucleotides in a double helix are **complementary**. The sequence of nitrogenous bases in one determines the sequence of the nitrogenous bases in the other. Complementary base pairing is of fundamental importance in molecular genetics.
6. Ten base pairs occur per turn of helix. The spacing between adjacent base pairs is 3.4 Å. The helix is 20 Å in diameter.
7. The double helix has two different grooves: a major groove and a minor groove.
8. DNA is negatively charged and dextrorotatory.
9. Molecular configuration of DNA is 3D.
10. DNA is acidic. For its compaction, it requires basic proteins.

Types of DNA. The model proposed by Watson and Crick is the DNA duplex model. It is a right handed spiral and is called **B-DNA**. In this model the base pairs lie at nearly right angles to the axis of helix. DNA may also exist in other alternative forms. The important features and differences among them are summarized below:

Several forms of DNA double helical structures

Type	Base pairs per turn	Rotation	Angle of rotation per base pair	Rise per base pair along helix axis.	Helical diameter	Pitch (Length of one helix)
A	11	Right handed	+33°	2.3 Å	26 Å	24.6 Å
B	10	Right handed	+36°	3.4 Å	20 Å	34 Å
Z	12	Left handed	-30° or -60° per dimer	3.8 Å	18.4 Å	45 Å

Linear and Circular DNA. DNA closed covalently at its two ends is called circular DNA. It occurs in nucleoid of bacteria and randomly in viruses, mitochondria and plastids. In linear DNA the two ends are free. It is seen in eukaryotic cells, some procaryotes and cell organelles. The DNA is coiled and super-coiled to get accomodated in small space. In prokaryotes DNA occurs in nucleoid and plasmids and is circular. In eukaryotes it occurs mainly in the chromatin of nucleus (linear) and small quantities are found in mitochondria and plastids (circular or linear). Circular DNA is naked, *i.e.*, no association with histone proteins though polyamides do occur. Linear DNA in eukaryotes is associated with histone proteins. Linear DNA without any association with histone proteins may occur in some prokaryotes *e.g.*, mycoplasma. In mitochondria and plastids as stated earlier it is usually circular and always naked.

Structure of DNA

DNA or deoxyribose nucleic acid is a helically twisted double chain polydeoxyribonucleotide macromolecule which forms the genetic material of all organisms with the exception of riboviruses. Single-stranded DNA occurs as a genetic material in some viruses (*e.g.*, f x 174). DNA is the largest **macromolecule** with a diameter of 2 nm (20 Å) and having a length in millimeters. A DNA molecule has two unbranched, spirally coiled complementary strands. The two spiral strands of DNA are collectively called **DNA duplex**. The two strands are not coiled upon each other but double strand is coiled upon itself or around a common axis like a rope stair case with solid steps twisted into a spiral. The DNA duplex comes to have two types of alternate grooves major (2.2nm wide) and minor (1.2nm wide). It has been suggested that minor grooves are the site of attachment of histone proteins and major grooves are the site of attachment of non-histone proteins [Strickberger]. One turn of the spiral has about 10 nucleotides on each strand of DNA. It occupies a distance of about 3.4 nm (34 Å) so that adjacent nucleotides or their bases are separated by a space of less than 0.34 nm (3.4 Å).

A deoxyribonucleotide of DNA is formed by cross-linking of three chemicals, *i.e.*, phosphoric acid (H_3PO_4), deoxyribose sugar ($C_5H_{10}O_4$) and a nitrogen base. The nitrogen bases belong to two groups, **purines** (9-membered double rings with nitrogen at 1, 3, 7 and 9 positions) and **pyrimidines** (six membered rings with nitrogen at 1 and 3 positions). DNA has two types of purines (**adenine** or A and **guanine** or G) and two types of pyrimidines (**cytosine** or C and **thymine** or T).

The backbone of a DNA chain or strand is built up of alternate deoxyribose and phosphoric acid groups. The phosphate group is connected to carbon 52 of the sugar residue of its own nucleotide and carbon 32 of the sugar residue of the next nucleotide by phosphodiester bonds. Phosphate

group provides acidity to the nucleic acids. Nitrogen bases lie at right angles to the longitudinal axis of DNA chains and are attached to carbon atom 12 of the sugars by glycosidic bonds. Pyrimidine is attached to deoxyribose by its N-atom at 1 position while a purine does so by N-atom at 9 position.

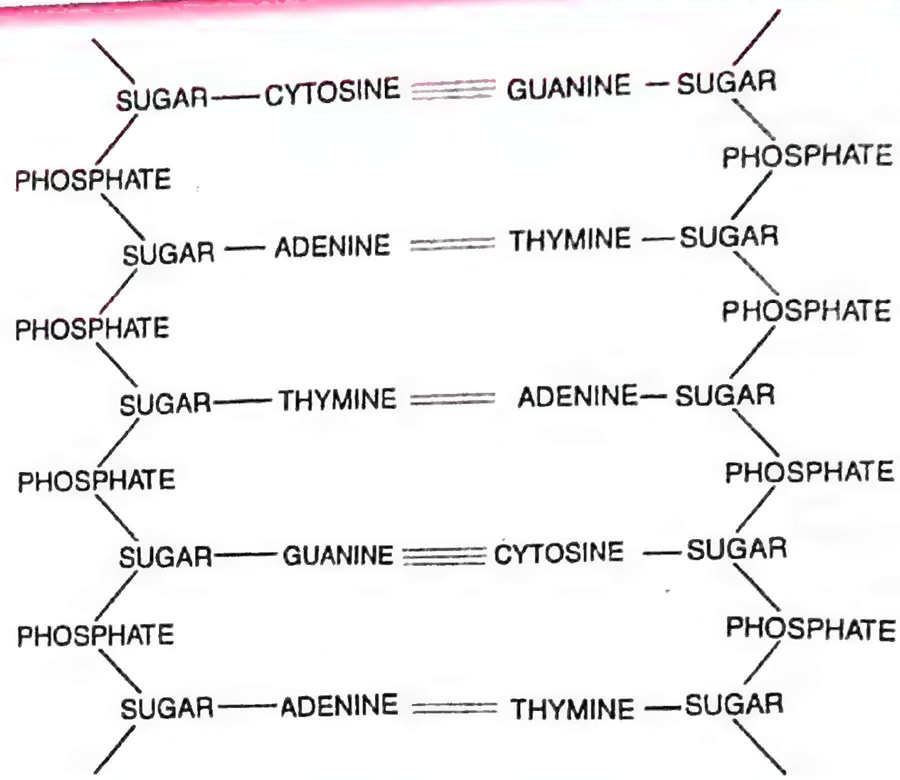


Fig. 9.3. Structure of DNA

The two DNA chains are **antiparallel,** *i.e.*, they run parallel but in opposite direction. In one chain the direction is 5′ → 3′ while in the opposite one it is 3′ → 5′. The two chains are held together by hydrogen bonds between their bases. Adenine (A), a purine of one chain lies exactly opposite thymine (T), a pyrimidine of the other chain. Similarly, cytosine (C) a pyramidine lies opposite guanine (G) a purine. Three hydrogen bonds occur between cytosine and guanine (C °G) at positions 1, 2, 6 of guanine and 2, 3, 4 of cytosine. There are two such hydrogen bonds between adenine and thymine (A=T) which are formed at positions 1 and 6 of adenine and 3 and 4 of thymine. Hydrogen bonds occur between hydrogen of one base and oxygen/nitrogen of the other base. The two DNA chains are not identical but are complementary, because of specific base pairing with a purine lying opposite a pyrimidine. This makes the two chains 2 nm thick. A purine- purine base pair will make it thicker while a pyrimidine- pyrimidine base pair will make it narrower than 2 nm. A larger sized purine, therefore, lies opposite the smaller-sized pyrimidine, A opposite T and C opposite G.

A bacteriophage known as ϕ 174 has 5386 nucleotides. Bacteriophage lambda has 48502 base pairs (bp), Escherichia coli has 4.6 x 10^6 bp, and haploid content of human DNA is 3.3 x 10^9 bp.

DNA Denaturation. The hydrogen bonds between the nitrogenous bases of complementary DNA strands can break if exposed to high temperature or very high or low *p*H. This is called **denaturation** or **melting of DNA**. The temperature range at which it occurs is about 70 – 100°C. The mid point of this range is called melting temperature and is represented by T_m. The area of DNA rich in A = T base pairs undergoes easy/early denaturation due to only two hydrogen bonds between the bases and thus this is the low melting area. On the other hand the area rich in G≡C base pairs is

Five special sites regions which are the single stranded-regions are seen in tRNA:— (i) **Anticodon** or **Terminal** or **Codon recognition site (Loop II).** It is made up of three unpaired nitrogen bases for recognising and attaching to the codon of mRNA. It is the most specific region of tRNA. **For initiation of translation there is a specific tRNA that is referred to as initiator tRNA.** (ii) **AA-Binding Site.** It lies at the 3' end opposite the anticodon and has CCA -OH group. It combines with specific amino acid in presence of ATP to form amino acyl tRNA. Amino acid or AA-binding site and anticodon site are the two **recognition sites** of tRNA. The acceptor arm is the base paired stem lying opposite the anticodon site and ends in an unpaired sequence whose free 2' or 3' OH group can be linked to an amino acid. The positions of the amino acids loops are numbered from 5' to 3' end. (iii) **T ψ C Loop** (Loop IV). It contains pseudouridine. The loop is the site for attaching to ribosomes. (iv) **DHU Loop** (Loop I). The loop contains dihydrouridine. It is binding site for aminoacyl synthetase enzyme. (v) **Extra Arm** (Loop III). It is the arm or loop which lies between T ψ C loop and anticodon loop. The most variable feature of tRNA is the extra arm or variable arm. Depending on the nature of the extra arm tRNAs can be divided into two classes.

Class I. tRNAs have small extra arm, consisting of only 3-5 bases. They represent ~75% of all tRNAs.

Class II. tRNAs have a large extra arm – it may even be the longest in the tRNA — with 13-21 bases and ~ 5 base pairs in the stem. The functional significance of the extra arm is unknown.

Functions. (i) tRNA — the **adapter molecule** transfers amino acids to ribosomes for synthesis of polypeptides. tRNAs carry specific amino acids (as per the codons of mRNA) at particular points during polypeptide synthesis. These amino acids are recognized by an enzyme aminoacyl synthetase. The codons of mRNA are recognised by anticodons of tRNAs. (ii) Peptidyl chains are held over the mRNAs by them.

3. **Messenger RNA** (mRNA). It is a long RNA which constitutes 2-5% of the total RNA content. It is synthesized inside the nucleus as a complementary strand to DNA and carries genetic information from chromosomal DNA to the cytoplasm for protein synthesis. The instructions are present in the base sequence of its nucleotides called the **genetic code.** A specific amino acid is coded by three adjacent nitrogen bases. mRNA gets attached to ribosome, and formation of polypeptide chain takes place over the ribosome. mRNA has a short life span and withers away after a few translations. Therefore, it has a high turnover. The mRNA has a methylated region (7 methyl guanosine) at the 5' terminus called the **cap** which helps in attachment with the ribosome. In eukaryotes this terminal guanine added at the 5' end of the mRNA is in reverse orientation from all other nucleotides as riboses of 7-methylguanosine and the terminal nucleotide are linked by a 5' to 5' triphosphate bridge. Bacterial mRNA is not capped. The cap is important in mRNA translation and protects mRNA from enzymatic degradation. This addition is catalysed by a nuclear enzyme guanylyl transferase. The cap is followed by an **initiation codon** usually (AUG) either immediately or after a small noncoding region. This is followed by a coding region and finally a **termination codon** (UAA, UAG, or UGA). After this there is a small region the poly A at the 3' terminus. This poly A is a stretch of adenine residues and is not coded in the DNA. The addition of this poly A to 3' end is catalysed by enzyme poly A polymerase. The poly A tail protects the mRNA molecule from enzymatic degradation in the cytoplasm and aids in export of mRNA from the nucleus, and translation. Bacterial mRNAs do not have poly A (De Robertis, Dubey and Maheshwari), but some authors believe it is present in prokaryotes also. An mRNA which specifies only a single polypeptide is called monocistronic, while that which has codons for more than one polypeptide is called **polycistronic,** *e.g.*, mRNA molecules which governs the metabolism of histidine codes for the synthesis of 10 special enzymes. Polycistronic mRNA is more common in prokaryotes. Eukaryotic mRNA is usually monocistronic. In some lower forms life span of mRNA is from a few minutes to a few hours (which makes it the shortest-lived RNA), whereas in

higher forms it has a life span of hours to even days. Young RBCs form haemoglobin even after their nucleus has degenerated meaning that mRNA has a life span of several days in them.

INFORMOSOMES. In eukaryotes mRNA is associated with protein, forming Ribonucleoprotein complexes. Some of these complexes remain free in the cytoplasm without being attached to the polyribosomes. These are named informosomes. They are very stable and can remain in the cell cytoplasm for several days, the stability being attributed by the presence of protein sheath around mRNA molecule. These informosomes are used by the cell in protein synthesis only when there is delay in translation.

Functions of mRNA. (i) mRNA carries coded information for protein synthesis (translation). (ii) Through reverse transcription it can form compact genes which are used in genetic engineering. The phenomenon also occurs in nature and has added certain genes in the genomes. (iii) It's cap region attaches it to ribosome.

Heterogenous nuclear RNA (HnRNA). In eukaryotes mRNA is synthesized as heterogenous nuclear RNA (HnRNA) inside the nucleus. These molecules are much bigger in size than RNA molecules and are not very stable.

4. **Genomic or Genetic RNA**. In most of the plant viruses, some animal viruses (Riboviruses) and in many bacteriophages. DNA is not found and RNA acts as hereditary material. This RNA may be single or double stranded. It may, however, not replicate directly, but form DNA in the host cell to produce RNA of its own types. Viroids and virusoids are other two classes of genetic RNA (explained under viruses).

5. **Small Nuclear RNA (snRNA)**. It is a small sized RNA with less than 300 nucleotides and is present in the nucleus. Each RNA is combined with 7-8 molecules of proteins to form small nuclear riboprotein or snRNP. It takes part in gene splicing, rRNA and mRNA processing. Gene splicing means removing the non coding region (introns) and joining the coding regions (exons) of mRNA during processing of the latter.

6. **Small Cytoplasmic RNA (scRNA)**. It is a small sized RNA occurring free in the cytoplasm. One such small cytoplasmic RNA is 7S and combines with 6 protein molecules to produce **signal recognition particle** or SRP which helps in binding a ribosome to endoplasmic reticulum for production of secretory proteins.

METABOLITES

Plants produce a number of chemicals. Some of the organic compounds like carbohydrates, fats, proteins, nucleic acids, chlorophylls, hemes are required for their basic metabolic processes and found throughout the plant kingdom. These organic compounds are called **primary metabolites** or biomolecules. These are produced in generous quantities and can easily be extracted from the plants.

Many plants, fungi and microbes of certain genera and families synthesize a number of organic compounds, which are not involved in primary metabolism (photosynthesis, respiration, protein and lipid metabolism) and seem to have no direct function in growth and development of plants. Such compounds are called **secondary metabolites** (secondary plant products or natural products). These compounds are produced in small quantities and their extraction from the plant is difficult and expensive. They accumulate in small quantities only in specific parts of plants. These are derivatives of primary metabolites. By the cultivation of plant cells in culture media, secondary metabolites can be produced on large scale.

Differences Between Primary and Secondary Metabolites

Primary Metabolites	Secondary Metabolites
1. These are biomolecules required for basic metabolic processes.	1. These are derivatives of primary metabolites, which are not involved in bast.
2. These are produced in generous quantities and can easily be extracted from the plant.	2. These are produced in small quantities and their extraction from the plant is difficult.
3. These are found throughout the plant kingdom.	3. Particular secondary metabolites are found in one plant species or families.
4. These are part of the basic molecular structure of the cell.	4. These are not part of the basic molecular structure of the cell.
5. They are highly useful to plant.	5. They have limited role in plant.
6. They are found from the start of plant life.	6. They are found at particular stages of development.

Role of Secondary metabolites

At the moment, we do not know the role or functions of all the secondary metabolites in host organisms. Some of the known functions are as follows :—

1. Some of them attract animals for pollination and seed dispersal.
2. They are used by the plants in their defense against herbivores and pathogens.
3. They act as agents of plant-plant competition.
4. They are used in making drugs, insecticides, flavours, pigments, scents, rubber, spices and other industrial materials like gums, resins for human welfare.

Types. These secondary plant products belong to three groups.

1. *Isoprenoids* or Terpenes, *e.g.*, rubber, steroids, essential oils.
2. *Nitrogen* containing compounds, *e.g.*, alkaloids, glucosinolates, glycosides, nonprotein amino acids.
3. *Phenolic compounds, e.g.*, lignin, tannins, coumarins, aflatoxins, flavonoids (anthocyanins).

Some important secondary metabolites produced through tissue culture.

Product	Source	Use
Azadirachtin	Neem leaves	Insecticidal
Caffeine	Coffee	CNS Stimulant
Codeine	Poppy	Cough suppressant
Digitoxin	*Digitalis*	Cardiac stimulant
Diosgenin	*Dioscorea*	Antifertility
Nicotine	Tobacco	Phytosanitary
Quinine	*Cinchona*	Antimalarial
Taxol	*Taxus baccata*	Anti cancer
Shikonin	*Lithospermum*	Red pigment used in lipsticks and dye for silk
Vinblastin	*Catharanthus* (Vinca)	Anticancer
Pyrethrin	*Chrysanthemum*	Insecticide
Jasmine	*Jasminum*	Perfume
Menthol	*Mentha*	Perfume, flavouring, drug

ENZYMES

Enzymes are proteinaceous substances which are capable of catalysing chemical reactions of biological origin without themselves undergoing any change. Therefore, they are called **biocatalysts.** Buchner isolated the first enzyme. There are numerous enzymes as every biochemical reaction is catalyzed by a separate enzyme. The enzymes neither start a chemical reaction nor change its equilibrium. They enhance the rate of reaction. Enzymes lower activation energy or energy required to overcome energy barrier of reaction.

Enzymes are mainly functional inside the living cells but they can be extracted from the cells and made to catalyse reactions outside the living cells. Some enzymes are secreted by living cells to perform extracellular catalysis. Digestive enzymes belong to this category. Enzymes functional outside the living cells are called **exoenzymes,** *e.g.,* enzymes present in digestive juices, lysozyme of tears. Enzymes functional inside living cells are known as **endoenzymes,** *e.g.,* enzymes of Krebs cycle (inside mitochondria), enzymes of glycolysis (inside cytoplasm).

Substrate is the biochemical which is acted upon by an enzyme and in case two biochemicals are involved in a reaction, the same are called **reactants.** The chemicals formed after the completion of a reaction are termed as **products.** The final products are also called **end products.**

Biological Importance

(i) Thousands of chemical reactions taking place in the body of a living organism are mediated by enzymes.

(ii) Enzymes are specialised catalysts operating at biological temperatures.

(iii) Enzyme mediated reactions do not require harsh treatment.

(iv) They are *pH* specific thus making reactions, requiring different *pH,* to occur in different parts of the body.

(v) They operate under favourable conditions thus force the organisms to live under favourable environment.

(vi) Enzyme formation is controlled by separate genes. Activation and repression of genes allow certain enzymes to be functional or nonfunctional in cells.

Economic Importance

(1) **ELISA** is an enzyme based test used for detection of diseases like AIDS. (2) **Endonucleases** are enzymes used in breaking DNA at specific sites. DNA fragments are employed in genetic engineering. (3) Enzyme complex zymase obtained from yeast is used in brewing or fermentation of alcoholic drinks. (4) **Detergents** contain protease for brighter washing of clothes and amylase for dish washing. (5) Trypsin is added to partially pre-digest baby foods. (6) **Streptokinase** is used in clearing blood clots inside vessels. (7) Diastase and other enzymes are used regularly by patients with deficient digestive juices. (8) Rennet tablets (from rennin of calf stomach) are used for preparation of cheese. Lactase and lipase are employed to provide proper consistency and flavour to cheese. (9) **Pectinase** is used for clearing fruit juices, retting of fibres and preparation of green coffee. (10) **Protease** enzyme is employed for chill proofing of beverages, degumming of silk, cleaning of hides, softening of bread and meat.

Chemical Nature of Enzymes

All enzymes are proteinaceous in nature with the exception of recently discovered RNA enzymes. All proteins are not enzymes. Some enzymes may additionally contain a non-protein group. Accordingly there are two types of enzymes, simple and conjugate.

Simple Enzyme. It is wholly made up of protein. Active site is formed by specific grouping of its own amino acids. Additional substance or group is absent, *e.g.*, pepsin, trypsin, urease.

Conjugate Enzyme. It is an enzyme formed of two parts namely **apoenzyme**, a protein part (*e.g.*, flavoprotein) and a nonprotein part named **cofactor.** The complete conjugate enzyme, consisting of an apoenzyme and a cofactor, is called **holoenzyme.** Active site is formed jointly by apoenzyme and cofactor.

Cofactor is a small, heat stable and dialysable part of conjugate enzyme which may be inorganic or organic in nature. **Coenzymes** are easily separable nonprotein organic cofactors. They are thermostable, low molecular weight substances. **Prosthetic groups** are nonprotein organic cofactors firmly attached to apoenzymes, *e.g.*, heme, biotin, pyridoxal phosphate. Heme acts as prosthetic group in cytochromes, haemoglobin, myoglobin, catalase and peroxidase. Both coenzyme and prosthetic group take part in group transfer reactions. Prosthetic group requires a single apoenzyme for picking up the group and transferring the same. Coenzymes require one apoenzyme for picking up the group and second apoenzyme for transferring the group *e.g.*, NAD^+, $NADP^+$, CoA. Coenzyme has three important functions (a) It is essential for bringing the substrate in contact with the enzyme (b) It picks up a product of the reaction, *e.g.*, hydrogen in case of NAD^+ (nicotinamide adenine dinucleotide) or $NADP^+$. (c) The product picked up by a coenzyme is transferred to another reactant.

Differences Between Coenzyme and Prosthetic Group

Coenzyme	*Prosthetic Group*
1. A non protein, organic group attached loosely to an apoenzyme.	1. A non protein, organic group attached firmly to an apoenzyme.
2. Requires two apoenzymes for picking and transfer of groups.	2. Require only one apoenzyme.

Most of the coenzymes are made of water soluble vitamins B and C *e.g.,* thiamine, riboflavin, nicotinamide, pyridoxine. **Inorganic cofactors** include ions of a variety of minerals *e.g.*, calcium, iron, copper, zinc, magnesium, manganese, potassium, nickel, molybdenum, selenium, cobalt. They usually function as **activators** *e.g.*, chloride ion stimulates activity of salivary amylase. Zinc is required for NAD^+ and $NADP^+$ activity. **Zinc is also a cofactor for the proteolytic enzyme carboxypeptidase.**

Active Site or Active Spot

The portion of enzyme molecule active in catalysing a chemical reaction is called **active site** or **active spot.** An enzyme may have one to several active sites. **An active site or spot is an area of the enzyme which is capable of attracting and holding particular substrate molecules by its specific charge, size and shape so as to allow the chemical change.** The active site serves as a lock or pocket or crevice into which the reactant (referred as substrate) fits in like a key. The point where substrate is bound on the active site is called substrate binding site. It fails to recognise other molecules. Active site consists of a few amino acids and their side groups, brought together in a particular fashion due to tertiary folding of a protein molecule and its association with the cofactor. For example, the active site for aldolase is glycine-histidine-alanine while that of pyruvic oxidase is aspartic acid-cysteine-alanine. The remaining amino acids maintain the shape of the enzyme molecule.

Nomenclature

All enzyme names should end in suffix – ase with few exceptions of some old names, *e.g.*, ptylin, pepsin, trypsin are still used. In modern system enzyme names are given after (i) **Substrate**

acted upon, *e.g.*, sucrase (after sucrose), lipase, proteinase, nuclease, peptidases, maltase (ii) **Chemical reaction,** *e.g.*, dehydrogenase, oxidase, carboxylase, decarboxylase, etc. The second category of names are group names. They are often qualified by the addition of the name of substrate, *e.g.*, succinic dehydrogenase, isocitric dehydrogenase, glutamate-pyruvate transaminase (transfers amino group ($-NH_2$) from glutamate to pyruvate), DNA polymerase (catalyses synthesis of DNA segments through polymerisation of deoxyribonucleotides).

Classification

The modern system of enzyme classification introduced by International Union of Biochemistry groups enzymes into the following six classes each with 4 – 13 subclasses and named accordingly by a four digit number :—

1. **Oxidoreductases** take part in oxidation and reduction reactions or transfer of electrons. Oxidoreductases are of three types – oxidases, dehydrogenases and reductases, *e.g.*, cytochrome oxidase (oxidises cytochrome), succinate dehydrogenase, nitrate reductase.

2. **Transferases** transfer a particular group from one molecule to another *e.g.*, glutamate-pyruvate transaminase (transfers amino group from glutamate to pyruvate during synthesis of alanine). The chemical group transfer does not occur in the free state.

3. **Hydrolases** break up large molecules into smaller ones with the help of hydrogen and hydroxyl groups of water molecules. The phenomenon is called hydrolysis. Digestive enzymes belong to this group, *e.g.*, amylase (hydrolysis of starch), sucrase, lactase.

4. **Lyases** cause cleavage, removal of groups without hydrolysis, addition of groups to double bonds or reverse, *e.g.*, histidine decarboxylase (breaks histidine to histamine and CO_2), aldolase (fructose-1, 6-diphosphate to dihydroxy acetone phosphate and glyceraldehyde phosphate). They facilitate removal of small molecules from a large substrate.

5. **Isomerases** cause rearrangement of molecular structure to effect isomeric changes. They are of three types, **isomerases** (aldose to ketose group or *vice-versa* like glucose 6-phosphate to fructose 6-phosphate), **epimerases** (change in position of one constituent or carbon group like xylulose phosphate to ribulose phosphate) and **mutases** (shifting the position of side group like glucose-6 phosphate to glucose 1-phosphate).

6. **Ligases** *(Synthetases* catalyse bonding of two chemicals with the help of energy obtained from ATP, *e.g.*, phosphoenol pyruvate or PEP carboxylase (combines phosphoenol pyruvate with carbon dioxide forming oxaloacetate accompanied by hydrolysis of ATP).

Characteristics of Enzymes and Factors Affecting Enzyme Activity

1. Enzymes are generally globular proteins having additional inorganic or organic substances for their activity. However, two types of RNA enzymes are known, ribozyme (for removing introns) and **ribonuclease-P** (for separating tRNAs from hnRNA). Other examples of RNA molecules acting as enzymes include L-19 RNA, RNA-ase T-1, virusoid and viroid.

2. Being proteinaceous, the enzymes are giant molecules with a molecular weight of 6000 (bacterial ferredoxin) to 4,600,000 (pyruvate dehydrogenase complex).

3. Enzymes are hydrophilic and form hydrosol in the free state.

4. Enzymes do not start a chemical reaction but increase the rate of chemical reaction. They do not change the equilibrium but bring about equilibrium very soon. They are not transformed or used up in the chemical reaction.

Catalysed reactions proceed at rates vastly higher than that of uncatalysed ones. When enzyme catalysed reactions are observed, the rate would be vastly higher than the same but uncatalysed reaction. For example

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \xrightarrow{\text{Carbonic anhydrase}} \underset{\text{carbonic acid}}{H_2CO_3}$$

In the absence of any enzyme this reaction is very slow, with about 200 molecules of H_2CO_3 being formed in an hour. However, by using the enzyme present within the cytoplasm called carbonic anhydrase, the reaction speeds dramatically with about 600, 000 molecules being formed every second. The enzyme has accelerated the reaction rate by about 10 million times.

5. The number of substrate molecules changed per minute by a molecule of enzyme is called **turn over number** (k_{cat}). The higher the turn-over number, the more efficient an enzyme is. It depends upon the number of active points present over an enzyme, precise collisions between reactants and the rate of removal of end products. The optimum turn-over number for enzyme carbonic anhydrase (enzyme present in RBCs) is 36 million, catalase 5 million, enzyme sucrase of invertase 10,000 and flavoprotein 50. Enzyme efficiency is usually much more than that of inorganic catalysts. For example, the rate of CO_2 hydration is 10 million times faster in the presence of enzyme carbonic anhydrase than in its absence.

6. All enzyme controlled reactions are reversible theoretically but reversibility is dependent upon energy requirements, availability of reactants, concentration of end products and *pH*.

7. They are highly specific in their action. For example, enzyme maltase acts on sugar maltose but not on lactose or sucrose. Different enzymes may act on the same substrate giving rise to different products. For example, raffinose gives rise to melibiose and fructose in the presence of enzyme sucrase while in the presence of enzyme melibiase it produces lactose and sucrose. Similarly an enzyme may act on different substrates, *e.g.*, sucrase can act on both sucrose and raffinose producing different end products.

8. All enzymes are heat sensitive or thermolabile, being active within a narrow range of temperature. The temperature at which an enzyme shows its highest activity is called **optimum temperature**. Most enzymes operate optimally between 25° – 35°C. Enzyme becomes inactive below **minimum temperature** and beyond **maximum temperature.** Low temperature preserves the enzymes in the inactive state so used in preservation of foods inside cold storages. Low temperature present inside cold storages prevents spoilage of food by two methods: (i) Inactivity of enzymes present inside food article and (ii) Nonactivity of microbes because their enzymes also become inactive at low temperature.

High temperature (50°C or more) destroys enzymes by causing their denaturation.

As opposed to warm blooded or homoeothermal animals (mammals, birds), there are cold blooded or poikilothermal animals (reptiles, amphibians, fishes, invertebrates) whose body temperature rises or falls with that of environmental temperature. These animals cannot live in very hot or very cold environment as enzyme functioning will be impaired. Because of this reason, frog seeks moist shady environment during summer and lies in an inactive form (hibernation) in the deeper layers of the soil during winter. **A general rule of thumb is that rate doubles or decreases by half for every 10°C change in either direction.**

9. Being made of proteins, enzymes are inactivated or denatured by all those substances and forces which destroy protein structure, *e.g.*, heavy metals, high energy, radiations. Cyanides, azides, iodoacetate, and salts of heavy metals destroy tertiary structure of enzymes by either combining with cofactor or a group of apoenzyme (–SH group, COOH). High energy radiations break hydrogen bonds, ionic bonds, and other weak linkages to destroy enzyme structure.

10. Each enzyme functions at a particular *pH* *e.g.*, pepsin (2 *pH*), salivary amylase (6.8 *pH*),

trypsin (8.5 pH). A rise or fall in pH reduces enzyme activity by changing the degree of ionization of side chains. Specificity of pH for enzyme activity is useful in regulating enzymes, *e.g.*, salivary amylase stops its activity in stomach where hydrochloric acid is secreted. On the other hand hydrochloric acid activates another enzyme pepsin from its precursor called pepsinogen. A change in pH may also start reverse reaction. Fumarase catalyse fumarate to malate at 6.2 pH and reverse at 7.5 pH. Most of the intracellular enzymes function at neutral pH.

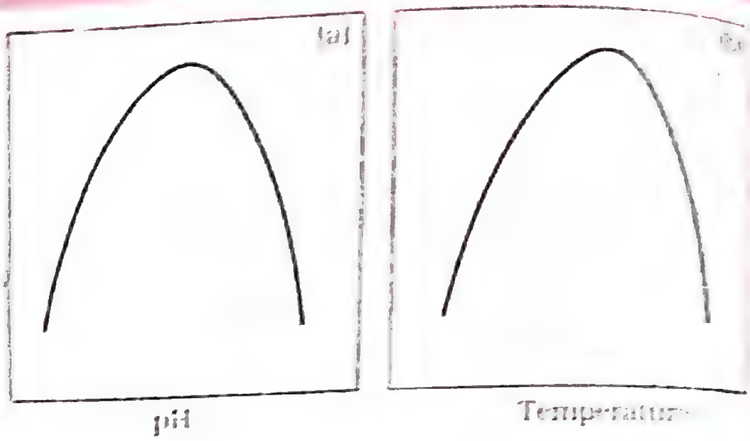


Fig. 9.3. Effect of change in : (a) pH (b) Temperature.

11. **Enzyme Substrate Complex.** The active sites of enzymes have a specific conformation for attracting and holding substrate. It usually possesses a crevice or pocket where the substrate fits in a complementary fashion. The two join to form a complex known as enzyme substrate complex (ES). The complexed state is short lived. Formation of enzyme substrate complex is essential for catalysis. The substrate is changed into products. The products remain complexed with the active site of the enzyme for a brief period. They soon separate and the active site is freed to perform another catalytic act. The greater the affinity of the enzyme for a substrate, the higher is the catalytic activity.

$$E + S \rightleftharpoons \underset{\text{Short lived}}{ES} \longrightarrow EP \rightleftharpoons E + P$$

12. Biochemical reactions are chain reactions occurring in quick succession. A team of enzymes work one after the other to accomplish such multistep reactions, *e.g.*, five enzymes for conversion of threonine to isoleucine.

13. **Enzyme Concentration.** The initial rate of a reaction (*i.e.*, the rate measured before sufficient product has been formed to permit reverse reaction to occur) rises with the increase in enzyme concentration upto a point called limiting or saturation point (point where enzyme is said to be saturated with the substrate). Beyond this, increase in enzyme concentration has little effect.

14. **Product Concentration.** If the products are allowed to remain in the area of the reaction, they may lower the rate of forward reaction by occupying active site of enzyme. Reverse reaction can also start.

15. **Activators.** They increase activity of enzymes (*e.g.*, chloride for salivary amylase), function as cofactors (*e.g.*, K^+, Mn^{2+}) and convert proenzymes to enzyme state. HCl of digestive juice changes proenzyme pepsinogen to enzyme pepsin. Pepsin also possesses **autocatalytic property** as it can also change pepsinogen to pepsin state.

16. **Substrate Concentration.** Increase in substrate concentration increases the rate of reaction by (a) occupation of more and more active sites by the substrate molecules and (b) higher number of

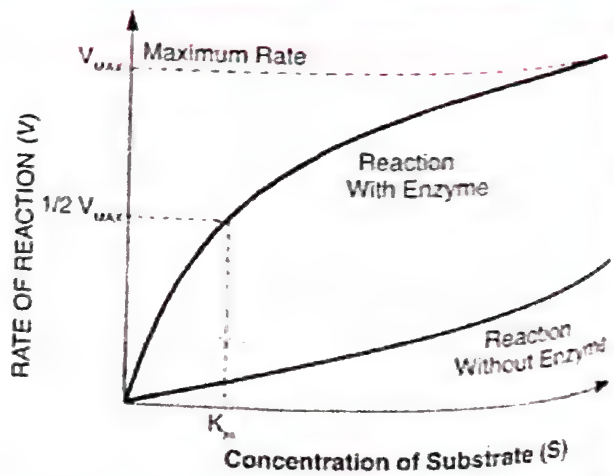


Fig. 9.4. Effect of substrate concentration on reaction velocity.

collisions between substrate molecules, if all other conditions are kept constant. The rise in velocity is quite high in the beginning. Subsequently, a stage is reached where. the enzyme molecules are fully saturated with no active site left free to bind additional substrate molecules. At this stage the initial velocity (V_i) becomes maximum (V_{max}) and does not increase further by increasing the substrate concentration This saturation effect is shown by all enzymes. If a graph is plotted for substrate concentration *versus* reaction velocity, it appears as a parabolic curve.

Michaelis Constant. (Michaelis Menten Constant, K_m). It is a mathematical derivation or constant which indicates the substrate concentration at which the chemical reaction catalysed by an enzyme attains half its maximum velocity. The substrate concentration which produces half maximal velocity, termed K_m value or Michaelis constant, may be determined experimentally by graphing V_i (initial velocity of reaction) as a function of (S) (substrate concentration). K_m can be considered as the concentration of the substrate at which half the active sites of enzyme are occupied by the substrate. K_m indicates affinity of the enzyme for its substrate. A high K_m indicates low affinity while a low K_m shows strong affinity. If an enzyme acts on more than one substrate it shows different K_m values for them. For example enzyme protease which acts on large number of proteins, K_m value will differ from protein to protein.

Allosteric enzymes do not show a typical Michaelis Menten constant or behaviour. The classical parabolic curve is replaced by a sigmoid saturation curve.

Activation Energy

Most of the chemical reactions do not start automatically because the reactant molecules have an **energy barrier** to become reactive. The energy barrier may be due to (i) Mutual repulsion due to presence of electrons over their surfaces. (ii) Solvation or holding of reactants in solution form by hydrogen bonds. (iii) Absence of precise collisions due to small reaction sites of reactive molecules. An external supply of energy is thus needed for the start of the chemical reaction which is called **activation energy.** Activation energy increases the kinetic energy of the system and brings about forceful collisions between the reactants. The requirement of activation energy is quite high. Activation energy required for thousands of chemical reactions occurring in cell at any time cannot be provided by living systems. Enzymes lower the activation energy required for a reaction. For example, in the presence of enzyme sucrase or invertase, hydrolysis of sucrose requires activation energy of 9000 cal/mole (instead of 32,000 cal/mole required in the absence of enzymes). This is achieved by four ways: (i) Desolvation or taking of reactants out of solution state. (ii) Establishing weak bonds between reactants and enzyme which releases energy called bond energy. (iii) Bringing the reactant molecules closer in the region of active sites of enzymes. (iv) Development of strain in the bonds of the reactants by electrophilic and nucleophilic attack.

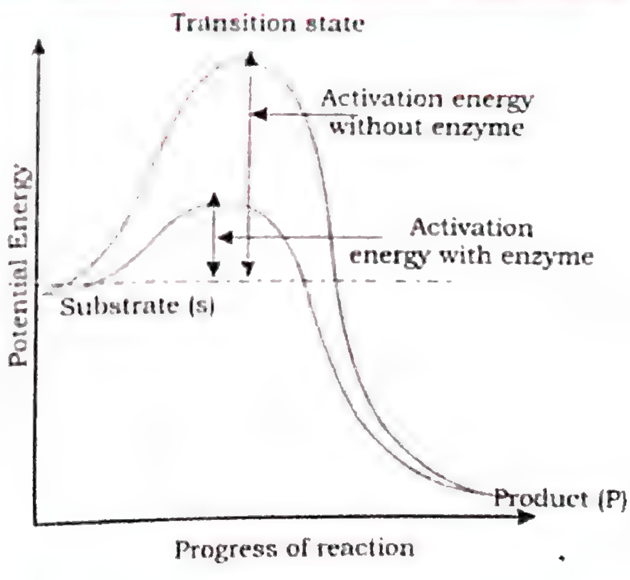


Fig. 9.4. Concept of activation energy.

Mode of Enzyme Action

There are two viewpoints by which enzymes are supposed to bring about chemical reaction.

1. **Lock and Key Hypothesis.** According to this hypothesis, both enzyme and substrate

molecules have specific geometrical shapes. The active site provides a rigid, preshaped template fitting with the size and shape of the substrate molecule. Substrate fits into the active site of an enzyme as the key fits into the lock, hence called lock-and-key model. The active sites also contain special groups having $-NH_2$, $-COOH$, $-SH$ for establishing contact with the substrate molecules. The contact is such that the substrate molecules or reactants come together causing the chemical change. Just as a lock can be opened by its specific key, a substrate molecule can be acted upon by a particular enzyme which explains the specificity of enzyme actions.

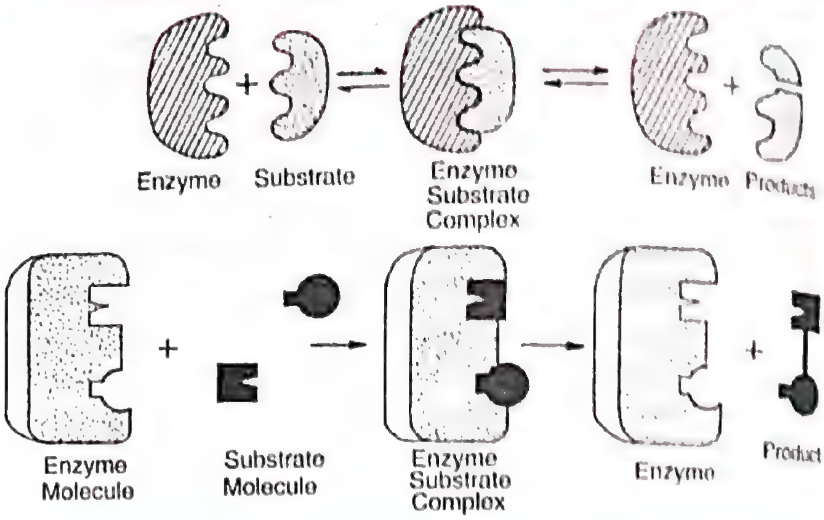


Fig. 9.5. Lock and key theory of enzyme action.

After coming in contact with the active site of the enzyme, the substrate molecules or reactants form a complex called **enzyme-substrate complex** where molecules of the substrate undergo chemical change. The products remain attached to the enzyme for some time so that an **enzyme product complex** is also formed. But the products are soon released and the freed enzyme is able to bind more substrate molecules.

$$\text{Enzyme} + \text{Substrate} \rightleftharpoons \text{Enzyme} - \text{Substrate Complex}$$

$$\text{Enzyme} - \text{Substrate Complex} \rightleftharpoons \text{Enzyme-Products Complex.}$$

$$\text{Enzyme} - \text{Products Complex} \rightleftharpoons \text{Enzyme} + \text{Products}$$

The chemical reactants do not cause any alteration in the composition or physiology of the enzyme and same enzyme molecule can be used again and again. This explains that small concentration of enzyme can be acted upon by large amount of substrate.

2. **Induced-Fit Theory.** It is modification of lock and key hypothesis according to which the active site of the enzyme contains two groups, **buttressing** and **catalytic.** The buttressing group is meant for supporting the substrate. The catalytic group is able to weaken the bonds of reactants by electrophilic and nucleophilic forces.

The two groups are normally at a distance. Active sites do not possess a rigid preformed structure on enzyme to fit the substrate. On the contrary when substrate comes in contact with the buttressing group, the active site of the enzyme undergoes conformational changes so as to bring the catalytic group opposite the substrate bonds to be broken. Catalytic group helps in bringing about chemical reaction and the substrate is converted into product. The product is unable to hold on the buttressing site due to change in its structure and bonds. Buttressing group reverts to its original position and the product is released.

Catalysts And Enzymes

Catalysts are inorganic substances which increase the rate of chemical reactions without themselves undergoing any change and without modifying the equilibrium of the reactions. Enzymes are similar chemicals which are biological in origin and operate in the biochemical world.

Similarities

1. Both of them remain unchanged chemically and quantitatively at the end of the reaction, so that they can be used over and over again.
2. Both are required in minute quantity as compared to their substrate.
3. Reactions controlled by both catalysts and enzymes are theoretically reversible though reversibility is dependent upon different kinetics.
4. Both do not change the equilibrium of the reaction.
5. Both of them increase the rate of chemical reaction but do not initiate the reaction.
6. Both lower the activation energy required for starting the chemical reaction.
7. Both form short lived complexes with the substrate molecules.
8. End products formed after reaction are not changed by catalysts and enzymes.

Dissimilarities

Inorganic Catalysts	*Enzymes*
1. They are inorganic in nature.	1. They are proteinaceous in nature.
2. There is little difference in the size of catalyst and substrate molecules.	2. Size of enzymes is quite large as compared to the size of substrate molecules.
3. Catalysts are small molecules or simple mineral ions with very low molecular weight.	3. They are complex macromolecules with three dimensional structure and a high molecular weight.
4. Catalysts operate in the nonliving or physical world.	4. They originate in biological world and mediate biochemical reactions.
5. They can catalyse diverse reactions but are less efficient.	5. Enzymes catalyse specific reactions of a single or only a few substrates and are highly efficient.
6. Functioning of catalysts is not controlled by regulator molecules.	6. Enzyme activity can be regulated by specific inhibiting substances which change the conformation of enzyme molecules.
7. Catalysts are not sensitive to small changes in temperature. They usually operate at high temperatures.	7. Enzymes are effective in a narrow range of temperature being inactivated at low temperatures (10°C and below) and denatured at high temperature (50°C and above).
8. Catalysts are not influenced by small changes in pH.	8. They function effectively only within a narrow range of *p*H, *i.e.*, optimal *p*H.
9. They are not affected by protein poisons and short wave radiations.	9. Enzymes are inactivated by a number of chemicals called protein poisons and get denatured by rays of shorter wave-length.

Proenzyme or Zymogen

Proenzyme is the inactive precursor of an enzyme. Zymogen is inactive precursor of proteolytic enzyme, e.g., pepsinogen for enzyme pepsin. Many enzymes are initially produced in the proenzyme or zymogen state which become reactive or active only at a particular pH, in the presence of substrate or after some special treatment *e.g.*, pepsinogen is changed to active enzyme pepsin in the presence of hydrochloric acid of gastric juice. Once pepsin is formed it further catalyze the conversion of proenzyme to pepsin. This is known as autocatalysis.

Allosteric Enzymes

They are the enzymes having areas called **allosteric sites** for different types of modulators which alter the conformation of active site thus making enzyme effective or ineffective. The substances which cause change in active sites are known as **modulators, allosteric substances or effectors.** The effectors are of two types— **activators** and **inhibitors.** Allosteric activator make active site operational while allosteric inhibitor brings about such a change in the active site that it becomes unable to combine with substrate molecules. For example, the enzyme phosphofructokinase is activated by ADP and inhibited by ATP.

Isoenzymes (Isozymes)

The multiple molecular forms of an enzyme occurring in the same organism and having a similar substrate activity are called isoenzymes or isozymes. a-amylase of wheat endosperm has 16 isozymes, lactic dehydrogenase has 5 isoenzymes in man, while alcohol dehydrogenase has 4 isozymes in maize. Isoenzymes differ in optimum activity and inhibition thus useful to organism in adapting to varied environmental conditions.

Inhibition of Enzyme Action

Enzymes are proteins and they can be inactivated by the agents that denature them. Chemical substances which inactivate the enzymes are called inhibitors. Reduction or stoppage of enzyme activity due to presence of adverse conditions or chemicals is called **enzyme inhibition**. It is of several types. They can be classified into two - Competitive and noncompetitive.

Competitive inhibition is caused by swamping of the active sites by a chemical which is similar in structure to the substrate but does not undergo chemical change. It is usually reversible. **Non-competitive inhibition** is caused by alteration of conformation of the enzyme by a chemical that binds to a site other than the active site. It may be reversible or irreversible.

Common types of enzymes inhibition are as follows:

(A) **Competitive Inhibition.** It is the inhibition of enzyme activity by the presence of a chemical that competes with the substrate for binding to the active site of the enzyme but do not undergo chemical change. The inhibitor chemical is also called **substrate analogue** or **competitive inhibitor** which resembles the substrate in structure. As inhibitor binds to the active site enzyme cannot participate in catalytic change of the substrate. This is similar to the jamming of a lock by a key similar to original one.

The affinity of the substrate for the enzyme is progressively decreased with the increase in concentration of inhibitor lowering the rate of enzymatic reaction. Thus, the **K_m is high, but V_{max} is the same in competitive inhibition**. Increase in concentration of substrate reverses effect of inhibitor. Thus competitive inhibition is a reversible inhibition.

Equilibrium constant for inhibitor binding is called K_i. A high K_i reduces enzyme activity while a low K_i allows enzyme activity to continue though at a reduced rate.

Classical example of competitive inhibition is reduction of activity of succinate dehydrogenase by malonate, oxaloacetate and other anions which resemble succinate in their structure.

Importance of Competitive inhibition

(i) It gives evidence for lock and key hypothesis of enzyme action.
(ii) Substrate analogues are not metabolised by enzymes.
(iii) Control of bacterial pathogens is through competitive inhibition, *e.g.*, sulpha drugs inhibit the synthesis of folic acid in bacteria by competing with p-amino benzoic acid (PABA) for the active site of enzyme. As animal cells obtain preformed folic acid, sulpha drugs do not harm them.

(B) **Non-competitive Inhibition.** It is an inhibition of enzyme activity by the presence of a substance that has no structural similarity with— the substrate. Probably the site of attachment of substrate and inhibitor are different. It is of two types— reversible (temporary) and irreversible (permanent). The **irreversible noncompetitive inhibitor** destroys or combines irreversibly with a functional group of enzyme essential for its catalytic function and can be removed only at the loss of enzymatic activity. For example, Cyanide inhibits the activity of cytochrome oxidase, a respiratory enzyme, by combining with its metallic ions though it does not have structural similarity with the substrate of the enzyme. Di-isopropyl fluorophosphate (DFP, a nerve gas) prevents impulse transfer by combining irreversibly with amino acid serine of acetylcholinesterase. Iodoacetamide inhibits enzymes having sulphahydryl (–SH) or imidazole group. In case of reversible-non-competitive inhibition, inhibitor can be removed from its binding site without affecting enzyme activity. Reversible inhibition can be eliminated by dilution and dialysis. **In non competitive inhibition V_{max} is lowered but K_m is kept constant.** Kinetic properties in both reversible and irreversible type are same.

(C) **Allosteric Modulation or Feed Back Inhibition.** This type of reversible inhibition is found in allosteric enzymes. The inhibitor is either a noncompetitive low molecular weight intermediate or product of a metabolic pathway having a chain of reactions involving a number of enzymes. Thus also called **end product** or **feed back inhibition.** The inhibitor also called **modulator,** is a substance that attaches with an allosteric enzyme at a site other than catalytic one but influences catalysis either by inhibiting or activating the same.

Examples of feed back or allosteric inhibition: (i) Stoppage of activity of enzyme hexokinase (glucokinase) by glucose-6-phosphate which is the product of reaction catalysed by it. (ii) Inhibition of threonine deaminase by isoleucine is another example. Amino acid isoleucine is formed in bacterium *Escherichia coli* in a 5-step reaction from threonine requiring separate enzyme for each step. When isoleucine accumulates beyond a **threshold value,** its further production stops as excess prevents enzyme threonine deaminase which is involved in the first step of the reaction (threonine to a-ketobutyrate).

Importance. (i) Inhibitors have a regulatory role on enzyme activity. (ii) Enzyme inhibitors have been used in the study of metabolic pathways. (iii) Inhibitors like sulpha drugs are used in controlling pathogenic activity, (iv) Use of inhibitors have shown the mechanism of enzyme action.

MULTIPLE CHOICE QUESTIONS

1. The four elements called "**Big-four**" which make up 95% of all elements found in a living system are
(1) C, H, O, N (2) C, H, O, P
(3) C, H, O, S (4) C, N, O, P

2. What is common between NAD and FAD ?
(1) Both are coenzymes.
(2) Both are derived from proteins
(3) Both act as oxygen carriers
(4) All of the above

3. Macromolecules are
(1) nucleic acids, proteins and polysaccharides
(2) nucleic acids and monosaccharides
(3) amino acids and polysaccharides
(4) amino acids, lipids and nucleotides

4. In ATP, the high energy bond is the one which links
(1) adenine with ribose
(2) adenine with phosphate
(3) phosphate to phosphate
(4) ribose with phosphate

5. Every carbohydrate is
(1) aldose or ketose
(2) ribose or deoxyribose
(3) hexose or pentose
(4) trioses or tetroses

6. Glucose is
(1) aldose hexose sugar
(2) ketose hexose sugar
(3) pyranose pentose sugar
(4) furanose pentose sugar

7. Oligosaccharides contain
(1) two monosaccharides
(2) 2–9 monosaccharides
(3) numerous monosaccharides
(4) no monosaccharides.

8. Reducing sugars are
(1) glucose, fructose, galactose, maltose and lactose
(2) glucose, sucrose and cellulose
(3) lactose, starch, glycogen and trehalose
(4) all of the above

9. Reducing sugars like glucose in Fehling solution reduce
(1) Fe^{++} to Fe^{+++} (2) Cu^{++} to Cu^{+}
(3) Hg^{++} to Hg^{+} (4) Cu^{+} to Cu^{++}

10. If deoxyribose sugar is supplemented with oxygen at second carbon atom, which one of these is formed ?
(1) Erythrose (2) Heptose
(3) Ribulose (4) Ribose

11. The sweetest sugar is
(1) fructose (2) glucose
(3) sucrose (4) monellin

12. Deoxyribose is
(1) $C_5H_{10}O_5$ (2) $C_5H_{10}O_4$
(3) $C_6H_{12}O_6$ (4) $C_6H_{12}O_5$

13. General formula of monosaccharides is
(1) $C_nH_{2n}O_n$ (2) $(CH_2O)_n$
(3) $C_n(H_2O)_n$ (4) All of these

14. General formula for disaccharide is
(1) C_nH_{2n+2} (2) $C_n(H_2O)_{n+1}$
(3) $C_n(H_2O)_{n-1}$ (4) $C_{12}H_{22}O_{12}$

15. The most common disaccharide has the molecular formula
(1) $C_{10}H_8O_9$ (2) $C_{12}H_{24}O_{12}$
(3) $C_{18}H_{22}O_{12}$ (4) $C_{12}H_{22}O_{11}$

16. The reagent used to detect sugar in the urine is
(1) Ninhydrin solution (2) Benzene
(3) Benedict's solution
(4) All of the above

17. Lactose is a disaccharide of
(1) glucose only
(2) glucose and fructose
(3) glucose and galactose
(4) all of the above

18. Maltose is hydrolysed in the presence of maltase to
(1) glucose (2) glucose & fructose
(3) fructose (4) glucose & galactose

19. Iodine test is used to detect
(1) fats (2) malaria
(3) typhoid (4) carbohydrates

20. Fructose is a ketose sugar and also called
(1) an aldose (2) fruit sugar
(3) cane sugar (4) corn sugar

21. Before a carbohydrate is utilized as an energy source, it gets first converted into

(1) disaccharide (2) oligosaccharide
(3) triose sugars (4) monosaccharide

22. How many atoms are there in pyranose ring?
(1) 5 (2) 3 (3) 6 (4) 7

23. Which of the following are all disaccharides ?
(1) Maltose, Sucrose, Lactose
(2) Maltose, Lactose, Glucose
(3) Glycogen, Lactose, Sucrose
(4) All of the above.

24. Invert sugar is mixture of
(1) maltose and fructose
(2) glucose and galactose
(3) glucose and fructose
(4) all of the above

25. A solution of *d*–glucose in water rotates the plane polarised light
(1) towards right (2) towards left
(3) towards either side
(4) none of the above

26. α and β – glucose differ in the orientation of – OH goup around
(1) C_3 (2) C_1 (3) C_5 (4) C_2

27. A sugar of animal origin is
(1) fructose (2) lactose
(3) DHAP (4) PGA

28. Monosaccharide found in nucleolus is
(1) pentose (2) tetrose
(3) erythrose (4) hexose

29. Why sucrose and not glucose is used to preserve fruit products ?
(1) Glucose is reactive as it has free CHO group
(2) Sucrose is more common in nature
(3) Sucrose is easily available and has both glucose and fructose
(4) None of the above

30. In ATP sugar is
(1) ribose (2) deoxyribose
(3) glucose (4) trioses.

31. Honey has three sugars. They are
(1) glucose, fructose and lactose
(2) glucose, galactose and inulin
(3) dextrose, laevulose and sucrose
(4) dextrose, lactose and ribose

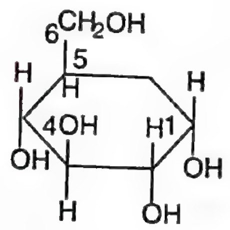
32. Non reducing sugars have
(1) free CHO group and free CO group
(2) neither free CO nor free CHO group
(3) free CHO and bound CO group
(4) free CO group and bound CHO group.

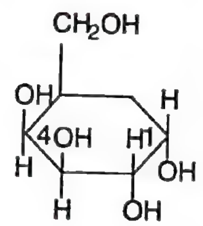
33. Milk tastes sour when kept in the open for sometime due to formation of
(1) carbonic acid (2) citric acid
(3) lactic acid (4) malic acid

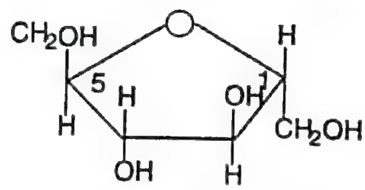
34. Which should be given to an athlete for instant energy ?
(1) Carbohydrates (2) Proteins
(3) Fats (4) Vitamins

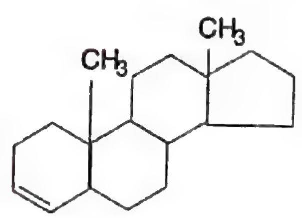
35. Prior to absorption, grape sugar is hydrolyzed by the enzyme
(1) lactase (2) maltase
(3) sucrose (4) none of these

36. Choose the correct molecule for glucose.

(1) 

(2) 

(3) 

(4) 

37. A fat molecule has
(1) 3 glycerol and one fatty acid molecule
(2) one glycerol and 3 fatty acid molecules
(3) one gycerol and one fatty acid molecule
(4) 3 glycerol and 3 fatty acid molecules

38. A skeleton of four interlocking carbon rings is found in
(1) steroids (2) waxes
(3) fats (4) glycerol

39. A fat molecule has three fatty acids. A Phospholipid molecule has how many fatty acids?
(1) 3 (2) 2 (3) 1 (4) 0

40. The most abundant lipid in cell membrane is
(1) phospholipid (2) steroid
(3) cholesterol (4) waxes

41. Amphipathy means
(1) presence of polar and non polar end in same molecule
(2) water and land habitat
(3) presence of dipolar Zwitter ions
(4) all wrong.

42. Essential fatty acids are
(1) not sythesized in plants
(2) not synthesized in animals
(3) five in number (4) both (2) and (3)

43. $C_nH_{2n}O_2$ is the general formula of
(1) carbohydrate (2) fatty acid
(3) fat (4) nucleic acid

44. In brain, common types of lipids are
(1) glycolipids (2) lipoproteins
(3) cholesterol (4) steroids

45. Which one is a saturated fatty acid ?
(1) Oleic acid (2) Linoleic acid
(3) Stearic acid (4) All

46. Which one is Tetraeonic (four double bond) fatty acid ?
(1) Arachidonic acid (2) Linoleic acid
(3) Oleic acid (4) Palmitic acid.

47. Which one is absent in wood ?
(1) Cellulose (2) Lignin
(3) Pectin (4) Fat

48. Essential fatty acids are present in large amount in
(1) butter (2) hydrogenated fats
(3) vegetable oils (4) desi ghee

49. Cholesterol is the precursor of
(1) progesterone (2) testosterone
(3) estradiol & cortisol (4) all of these

50. Waxes are esters of higher fatty acids with long chain of
(1) monohydric alcohols
(2) dihydric alcohols
(3) trihydric alcohols (4) all of these

51. Lecithin and cephalins are
(1) nucleic acid (2) phospholipid
(3) carbohydrate (4) sphingolipids

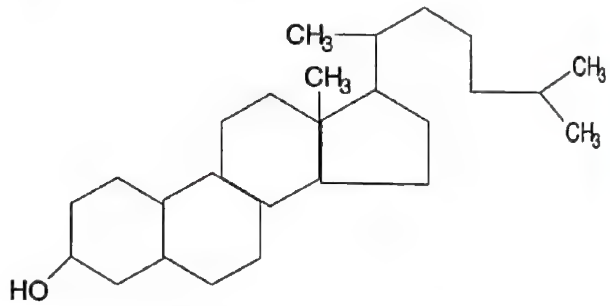
52. Bee wax mainly consists of
(1) myricyl palmitate (2) myricyl cerotate
(3) cetyl palmitate (4) none of these.

53. Which one of the following gives maximum energy in metabolic processes ?
(1) Proteins (2) Nucleic acids
(3) Fats (4) Carbohydrates

54. A fatty acid or amino acid is called essential when
(1) cell is unable to synthesize it on its own
(2) cell requires it badly and so make it on its own
(3) cell badly needs it but does not have the capacity to synthesize it and obtain it from the diet.
(4) cell needs it and gets it from adjacent cells

55. Cholesterol is a
(1) simple lipid (2) phospholipid
(3) derived lipid (4) glycolipid

56. This molecule is related to



(1) cholesterol (2) phospholipid
(3) lipoprotein (4) mucoprotein

57. $CH_3(CH_2)_7CH = CH(CH_2)_7COOH$ is formula of
(1) oxalosuccinate (2) oleic acid
(3) linolenic acid (4) α-ketoglutarate

58. Lipids are translocated through blood by
(1) glycolipids (2) sulpholipids
(3) lipo proteins (4) phospholipids

59. Which of the following picks up excess cholesterol from plasma and transports it to the liver for disposal?
(1) LDL (2) HDL
(3) Both (1) & (2) (4) glycolipid

60. Which amino acid has no asymmetric carbon atom ?
(1) Glycine (2) Alanine
(3) Proline (4) Threonine

61. Which one of the following sets have combi-

nation of an acidic, basic and neutral amino acids respectively ?
(1) Glutamate—Lysine—Glycine
(2) Arg—Asp—Val.
(3) Asp—Val—Phe (4) Phe—Lys—Arg.

62. The first amino acid taking part in protein synthesis is
(1) Met (2) Val (3) Arg (4) Tryp

63. Sulphur containing amino acids are
(1) valine, lysine and cystine
(2) tryptophan, glutamic acid, aspartic acid
(3) citrulline, methionine and glumaric acid
(4) cysteine, cystine, methionine.

64. Essential amino acids are those which our body can not synthesize but we require them badly and, therefore, we take them from diet. These are usually seven in number and are
(1) leucine, lysine, isoleucine, valine, tryptophan, phenylalanine, methionine
(2) leucine–lysine–isoleucine–valine–tryptophan–phenylalanine–glycine
(3) gly–ala–val–his–try–asp–met
(4) none of the above

65. An amino acid which is precursor of Indole 3-acetic acid (Auxin) is
(1) glycine (2) valine
(3) glutamic (4) tryptophan

66. Living organisms have
(1) α-amino acids and L-sugars
(2) L-amino acids and D-sugar
(3) D-amino acids and L-sugar.
(4) α-amino acids and α-sugars.

67. Which one is an amino acid ?
(1) $CH_3-CH(NH_2)-C(=O)-OH$
(2) $CH_3-CH_2-C(=O)-O-NH_4$
(3) $CH_3-CH_2-C(=O)-NH_2$
(4) $CH_3-CH-NH_2-C(=O)-Cl$

68. Which of the two groups of following formula involved in peptide linkage between different amino acids ?

$$H_2N^1 - \underset{\substack{|\\R^4}}{\overset{\substack{H^2\\|}}{C}} - COOH^3$$

(1) 2 and 3 (2) 1 and 3
(3) 1 and 4 (4) 2 and 4

69. Amino acids usually exist in the form of Zwitter ions. This means that they consist of
(1) the basic NH_2 group and acidic COOH group
(2) the basic NH_3^+ group and the acidic COO^- group
(3) basic COO^- group & acidic NH_3^- group
(4) none of the above

70. The peptide linkage is
(1) $CONH_2$ (2) —CO.NH
(3) $—COONH_2$ (4) —CH—NH

71. Precursor of niacin is
(1) lysine (2) threonine
(3) tryptophan (4) glycine

72. The following one is smallest.
(1) Maltose (2) Cellulose
(3) Glycine (4) Cellbiose

73. Two of the following amino acids are needed for growth only and are not essential for adults.
(1) Cysteine and cystine
(2) Leucine and valine
(3) Tryptophan and isoleucine
(4) Arginine and histidine

74. In branching of molecules of starch, which glycosidic bond occurs ?
(1) α-1–4 (2) β, 1–4
(3) β, 1–6 (4) α, 1–6

75. In amylose glucose units are linked by
(1) α–1–4 linkages
(2) α–1–6 linkages
(3) both α–1–4 and α–1–6 linkages
(4) all of the above.

76. Which is an unbranched glucosan (hexagon) ?
(1) Cellulose (2) Starch
(3) Glycogen (4) All the above

77. The monomer units in starch are
(1) Pyranose fructose (2) Furanose
(3) β-D-Glucose (4) α-D-Glucose

78. Chitin forming exoskeleton in arthropods is second most abundant carbohydrate on this earth. It is a
(1) storage sulphur containing polysaccharide
(2) nitrogen containing structural homo-polysaccharide
(3) mucopolysaccharide
(4) structural oligosaccharide

79. Which of the following carbohydrates gives a dark blue colour with iodine ?
(1) Amylopectin (2) Cellulose
(3) Starch (4) None of these

80. The starch and glycogen are two most suitable storage polysaccharides because
(1) they occupy less space
(2) they do not disturb *p*H of cell
(3) they cannot pass through cell membrane being larger in size
(4) all of the above

81. Hyaluronic acid is a heteropolysaccharide and has acytyl glucosamine + glucoronic acid. It is a cementing material and found in
(1) ovum and synovial fluid
(2) vitreous humour
(3) skin (4) all of the above

82. A polysaccharide used as solidyfying agent is
(1) pectin (2) silica gel
(3) peptone (4) agar

83. Which is incorrect regarding glycogen ?
(1) Glycogen is analogous to starch
(2) It is non reducing sugar
(3) It is a structural polysaccharide
(4) It gives red colour with iodine solution

84. Which is a wrong statement ?
(1) Cellulose is the most abundant homopolysaccharide.
(2) Waxes are simple lipids.
(3) Glycogen and glucose are two common carbohydrates in animals.
(4) Steroid is a fatty acid

85. The polysaccharide used in evaluating the function of human nephron is attained from the ________ of Dahlia plant.
(1) root (2) stem
(3) seeds (4) fruit

86. A polysaccharide of cartilage is
(1) chondrin (2) ossein
(3) chondriotin sulphate (4) cartilagin

87. Nucleoprotein is
(1) structural protein (2) simple protein
(3) conjugated protein (4) fibrous protein

88. 'P' protein refers to
(1) phloem protein (2) plasma protein
(3) platelet protein (4) primary protein

89. Primary structure of protein is due to
(1) hydrogen bonds (2) peptide bonds
(3) —S—S linkages (4) ionic bonds

90. A storage protein is
(1) keratin (2) collagen
(3) haemoglobin (4) glutelin

91. Which chemical characteristic is not common to all living beings ?
(1) Types of proteins present in the body
(2) Similar triplet code for amino acids
(3) Energy is stored in high phosphate bonds.
(4) None of the above

92. The most abundant protein in the plant world is found in
(1) chloroplasts (2) mitochondria
(3) viruses (4) roots

93. That proteins are made up of amino acids and sequence of amino acids in protein was determined by a two time Nobel laureate
(1) Sanger (2) Sumner
(3) Pauling (4) Wilkins

94. Immunoglobulins (antibodies) of the blood plasma are
(1) glycoproteins (2) lipoproteins
(3) flavoproteins (4) all of these

95. Which makes the protein active and globular / Which structure provides specific shape and function to the protein ?
(1) Primary structure
(2) Secondary structure
(3) Tertiary structure
(4) Sulphide bonds and peptide bonds

96. **Most abundant protein** on earth is
(1) keratin (2) rubisco
(3) RuBP (4) fibrinogen

97. Two types of secondary structures of proteins are
(1) α–helix and β–helix
(2) α–helix and β–pleated sheet
(3) β–helix and β–pleated sheet
(4) Helix and rod.

98. The most diverse chemical is
(1) phospholipid (2) cellulose
(3) proteins (4) carbohydrates

99. The enormous diversity of protein molecules is due to the diversity of
(1) amino groups in amino acids
(2) R groups in amino acids
(3) amino acid sequences
(4) peptide bonds

100. In β–pleated protein, polypeptide chains lie parallely and held together by
(1) S—S bond (2) CONH bond
(3) H—bond (4) None of these

101. The major fibrous protein of connective tissue is
(1) myosin (2) myoglobin
(3) collagen (4) keratin

102. The protein of red muscles to store oxygen is
(1) haemoglobin (2) myoglobin
(3) myosin (4) actin

103. The helical structure of proteins is stabilised by
(1) glycosidic bonds
(2) dipeptide bonds
(3) hydrogen bonds (4) all of these

104. The sequence in which amino acids are linked to one another in linear sequence in a protein molecule is called its
(1) primary structure
(2) secondary structure
(3) tertiary structure (4) all of these

105. Formation of proteins is a type of
(1) dehydration synthesis
(2) dehydrogenation
(3) hydration synthesis
(4) hydrogenation

106. Point out the incorrect statement regarding proteins.
(1) Most of enzymes and many hormones are proteins.
(2) Proteins are structural components of membrane.
(3) Proteins are high energy yielding compounds.
(4) Immunoglobulins are proteins

107. Denaturation of proteins change its
(1) structure and properties
(2) structure and not property
(3) property but not structure
(4) neither structure not property.

108. Natural silk fibre is
(1) polyester (2) protein
(3) lipid (4) polysaccharide

109. Keratin and chitin are chemically
(1) carbohydrates & are functionally similar
(2) carbohydrates but functionally different
(3) proteins and functionally similar
(4) different but functionally similar.

110. Which of the following groups is present invariably at the two terminals of protein ?
(1) Methyl and ethyl
(2) Aldehyde and ketone
(3) Amino and carboxylic
(4) Acid and alcohol

111. The spider webs are built of
(1) fat (2) fibroin protein
(3) protamines (4) proteoglycans

112. Structural proteins are usually
(1) fibrous (2) globular
(3) enzymatic (4) soluble

113. Biochemical reagent that specifically detects a C═O group in a biomolecule will give a positive test with
(1) protein (2) carbohydrate
(3) fats (4) all of these

114. Sulphur is needed for
(1) glucose formation (2) ATP synthesis
(3) DNA duplication (4) protein synthesis

115. Glycosidic bond is
(1) C—O—C (2) CONH
(3) >C ═O (4) CHO

116. Cellulose in plant cell wall is made up of
(1) unbranched chain of glucose molecules linked by α, 1→ 6 glycosidic bond
(2) unbranched chain of glucose molecules linked by β, 1→ 4 glycosidic bond
(3) branched chain of glucose molecules linked by α, → 6 glycosidic bond in straight chain & β→1,4 at the site of branching
(4) branched chains have α→1,4 bond and β → 1,6 glycosidic bonds both

117. A carbohydrate unique to arthropods is
(1) chitin (2) hyaluronic acid
(3) chondriotin sulphate
(4) waxes

118. Which one of the following has no free aldehyde or ketone group?
(1) Fructose (2) Maltose
(3) Sucrose (4) Galactose

119. EFA is
(1) linoleic acid (2) oleic acid
(3) palmitic acid (4) caproic acid

120. ^{18}C unsaturated fatty acid with three double bonds is
(1) oleic acid (2) linoleic acid
(3) linolenic acid (4) arachidonic acid

121. Arachidonic acid is
(1) non-essential fatty acid (NEFA)
(2) polyunsaturated fatty acid (PUFA)
(3) both (1) and (2)
(4) saturated fatty acid

122. Phospholipids are
(1) amphipathic (2) amphibolic
(3) hydrophobic (4) none of these

123. Select the odd from the following.
(1) Glutamic acid (2) Stearic acid
(3) Butyric acid (4) Oleic acid

124. Excess of amino acids are stored in
(1) kidney (2) liver
(3) spleen (4) none

125. The difference between one amino acid and another is found in the
(1) Carboxyl Group (2) Amino group
(3) R group (4) Peptide Bond

126. Relationship between amino acid and protein is similar to one found between
(1) glucose and fructose
(2) nucleotides and nucleic acid
(3) nucleosides and nucleic acid
(4) purines and pyrimidines

127. Non essential amino acid is
(1) not needed in the diet
(2) not essential for growth
(3) not synthesised in body
(4) not required for protein synthesis

*128. If the molecular mass of an amino acid is 150 daltons, the molecular mass of a tripeptide will be
(1) 450 (2) 486 (3) 504 (4) 414

129. α-helix is stabilized by H-bonds between the
(1) NH and CO group of side chain
(2) NH and CO group of main chain
(3) NH and NH group of same chain
(4) NH and COOH groups of all chains

130. **Largest macromolecule** in cell is
(1) DNA (2) cellulose
(3) chitin (4) glycogen

131. Histones are
(1) basic proteins (2) glycoproteins
(3) acid proteins (4) mucoproteins

132. All enzymes are
(1) either pure or conjugated proteins
(2) pure proteins
(3) conjugated proteins
(4) inorganic catalysts

133. Quarternary structure of protein is
(1) arrangement of amino acids in polypeptide chain
(2) inter-relationship of amino acids in a polypeptide chain
(3) inter-relation between polypeptide chains of a protein having more than two polypeptide chains
(4) all of the above

134. Which of the following is nutritionally essential amino acid for humans ?
(1) Arginine (2) Aspartic acid
(3) Glycine (4) Phenylalanine

135. Enzymes (Biocatalysts) were discovered accidently in yeast cell extract by a biochemist for which he was awarded Nobel Prize was
(1) Kuhne (2) Pasteur
(3) Buchner (4) Sumner

136. Most of the enzymes when secreted are in inactive form (called proenzymes or zymogens) otherwise they will mainly destroy
(1) cell proteins
(2) cell DNA
(3) cell mitochondria
(4) cell wall and membrane

137. Enzymes are required in traces because they
(1) have high turnover number
(2) remain unused at the end of reaction and are reused
(3) show cascade effect
(4) all correct

*128. Tripeptide is formed by the condensation of 3 amino acids with loss of $2H_2O$ molecules. The molecular mass of 2 water molecules is $18 \times 2 = 36$. Therefore, tripeptide mass will be $(150 \times 3) - 36 = 414$.

138. An enzyme extract when subjected to electric field, separates into two fractions each catalysing the same reaction. These fractions are
(1) allosteric enzymes (2) isoenzymes
(3) inducible enzymes (4) coenzymes

139. The inorganic part of enzyme is known as
(1) holoenzyme (2) coenzyme
(3) apoenzyme (4) activator

140. All enzymes are not proteins. Which of the following enzyme is not a protein ?
(1) Ribozyme discovered by Cech (1981)
(2) Ribonuclease discovered by Altman (1983)
(3) Both correct
(4) DNA/RNA polymerase.

141. The digestive enzymes are
(1) oxidoreductases (2) transferases
(3) hydrolases (4) ligases

142. Coenzyme is
(1) always a protein (2) often a vitamin
(3) inorganic (4) often a metal

143. Why is heat used to sterilize nonliving objects in tissue culture ?
(1) Proteins are denatured at temperature above 55ºC
(2) Proteins lose their primary structures due to break down of hydrogen bonds
(3) Both correct
(4) Only (1) is correct.

144. A high fever is dangerous to a human because
(1) proteins are used up quickly
(2) fats are oxidised
(3) enzymes are denatured
(4) BMR is Lowered

145. According to IUB system, isomerases belong to which class ?
(1) I (2) III (3) V (4) IV

146. IUB had divided enzymes into how many classes ?
(1) 6 (2) 5 (3) 8 (4) 4

147. Enzymes which breakdown compounds without using H_2O are called
(1) lyases (2) ligases
(3) hydrolases (4) proteases

148. Which part of enzyme in a holoenzyme (conjugate enzyme) determines specificiy of enzyme ?
(1) Apoenzyme (2) Prosthetic group
(3) Metalo activator (4) None of these

149. The function of an enzyme is to
(1) cause chemical reaction
(2) change the rate of chemical reaction
(3) change the equilibrium
(4) change the directions of reactions

150. Which of the following is correct in an enzyme-controlled reaction ?
(1) $E+S \rightleftharpoons E+P$
(2) $E+S \rightleftharpoons ES \rightleftharpoons EP \rightleftharpoons E+P$
(3) $E+S \rightleftharpoons ES \rightleftharpoons E$
(4) $E+S \rightleftharpoons P \rightleftharpoons E+P$

151. Enzymes have
(1) same *p*H and temperature optima
(2) same *p*H but different temperature optima
(3) different *p*H but same temperature optima
(4) all wrong

152. Feed back term refers to
(1) effect of substrate on rate of enzymatic reaction
(2) effect of end product on rate of reaction
(3) effect of enzyme conccentration on rate of reaction
(4) effect of external compound on rate of reaction

153. Enzymes promote rate of chemical reaction by
(1) lowering energy of activation
(2) increasing energy of activation
(3) maintaining energy of activation
(4) without affecting activation energy but increasing reaction time.

154. Enzymes get denatured (killed) due to
(1) sudden change in *p*H
(2) decrease in temperature
(3) decrease in hydration
(4) all of the above

155. Cyanide kills animals by inhibiting cytochrome oxidase (an enzyme of respiration) by binding irreversibly with copper. It does not bind with active site. This is an example of
(1) competitive inhibition
(2) non competitive inhibition
(3) feed back inhibition.
(4) all of the above

156. In competitive inhibition
(1) inhibitor resembles the substrate in molecular structure
(2) inhibitor binds to allosteric site and block it
(3) inhibitor has no effect on active site
(4) all correct

157. Prosthetic group is a part of holoenzyme it is
(1) inorganic part loosely attached
(2) accessory non protein organic substance attached firmly
(3) organic part attached loosely
(4) none of the above.

158. Coenzyme is a part of enzyme
(1) inorganic metal activator
(2) nonprotein organic part attached firmly
(3) nonprotein organic part attached loosely
(4) vitamin A

159. Which inactivates an enzyme by occupying its active site ?
(1) competitive inhibitor
(2) allosteric inhibitor
(3) non-competitive inhibitor
(4) all of the above.

160. Which one inactivates an enzyme by changing the enzyme shape ?
(1) Allosteric inhibitor
(2) Competitive inhibitor
(3) Coenzyme
(4) Irreversible inhibitor

161. Turn over number of an enzyme means
(1) number of substrate molecules acted upon by one molecule of an enzyme per minute
(2) number of enzyme molecules acting on one molecule of substrate per minute
(3) number of molecules of end product produced by an enzyme in one minute.
(4) number of substrate molecules acted upon by an enzyme per second.

162. The value of K_m (Michaelis-Menten constant) varies from 10^{-1} to 10^{-6} M but for allosteric enzymes, there is no constant K_m value. This K_m is
(1) substrate concentration at which the enzymatic reaction attains half its maximum velocity $\left(\frac{1}{2}V_{max}\right)$
(2) enzyme concentration at which the reaction attains $\frac{1}{2}V_{max}$
(3) end product concentration at which reaction attains $\frac{1}{2}V_{max}$
(4) none of the above statements is correct

163. The lower value of K_m means
(1) higher substrate affinity of enzyme
(2) higher enzyme activity
(3) no effect on reaction
(4) lower the affinity of enzyme with substrate

164. In a diluted starch solution, α-salivary amylase is added at *p*H 1.6 and kept at 35ºC for half an hour and then iodine solution is added, what would be the result ?
(1) There will be a red colour
(2) There will be a blue solution
(3) Solution will be clear and colourless
(4) The solution will be sweet

165. Some enzymes when secreted are in inactive state. Such enzymes in inactive state are called
(1) isoenzymes (2) coenzymes
(3) zymogens (4) apoenzyme

166. Which is best evidence for Lock and Key theory (Template theory) ?
(1) Competitive inhibition
(2) Feed back inhibition
(3) Allosteric competition
(4) Non-competitive inhibition

167. Which is an enzyme that joins two segments of replicated DNA ?
(1) Ligase (2) Lyase
(3) Endonuclease (4) Topoisomerase

168. Apoenzyme and coenzyme collectively produce
(1) holoenzyme
(2) enzyme-product complex
(3) cofactor (4) prosthetic group

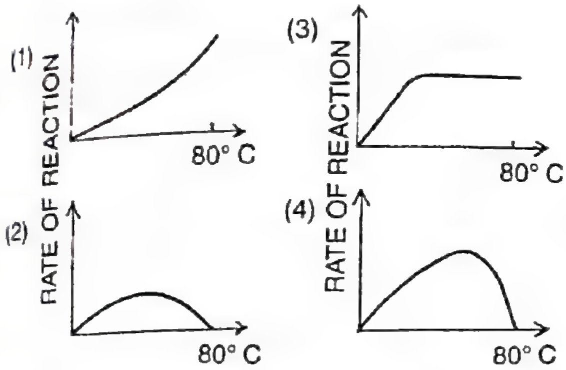
169. Which vitamin is incorporated into the structure of NAD/NADP ?
(1) Riboflavin (2) Vitamin PP
(3) Nicotinic acid (4) All correct

170. Mutases and epimerases are
(1) isomerases (2) hydrolases
(3) lyases (4) ligases

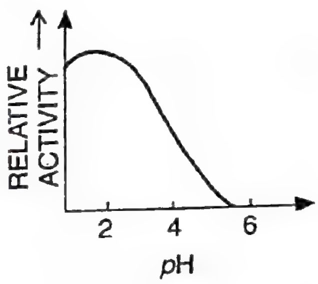
171. The enzymatic function of a protein is due to

(1) primary structure
(2) tertiary structure
(3) secondary structure
(4) helix structure

172. Which one of the following diagrams represents the most common relationship between temperature and enzyme activity when the temperature is raised gradually from 0—80°C ?



173. The enzyme depicted in the below graph is



(1) amylase (2) pepsin
(3) trypsin
(4) alcohol dehydrogenase

174. Lipase acting on fats breaks
(1) ester bond (2) peptide bond
(3) hydrogen bond (4) glyosidic bond

175. Earliest known enzyme was
(1) sucrase (2) zymase
(3) diastase (4) urease

176. No cell could live without
(1) enzymes (2) cytochromes
(3) chloroplast (4) phytochromes

177. The protein part of conjugated enzyme is called
(1) holoenzyme (2) coenzyme
(3) prosthetic group (4) apoenzyme

178. Enzymes that catalyse endergonic synthesis coupled with exergonic hydrolysis of ATP are
(1) Ligases (2) Lyases
(3) Hydrolases (4) Oxidoreductase

179. Cofactors are
(1) non-protein organic molecules
(2) vitamins (3) metallic ions
(4) all of the above

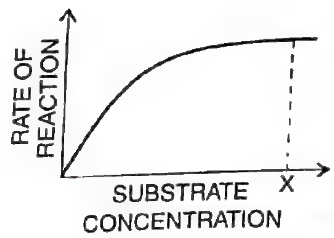
180. The region that contains the binding and catalytic sites is termed as
(1) active site (2) apoenzyme
(3) holoenzyme (4) allosteric site

181. Enzymes/Proteins contain regulatory sites called
(1) allosteric sites (2) active sites
(3) folding sites (4) buttressing site

182. The enzyme concerned with transfer of electrons is
(1) oxidoreductases (2) cytochrome oxidase
(3) dehydrogenase (4) all of these

183. Substances which bring about changes in allosteric sites are called
(1) activators (2) inhibitors
(3) promoters (4) modulators

184. The given graph is showing the relationship between the rate of enzyme reaction and concentration of substrate. At concentration of substrate greater than X, the



(1) rate of reaction is limited by the enzyme concentration
(2) substrate has an inhibitory effect
(3) rate of reaction tends towards zero
(4) product of the reaction has an inhibitory effect.

185. In case of competitive inhibition of an enzyme,
(1) V_{max} is increased
(2) K_m is increased
(3) Extent of inhibition remains the same in high substrate concentrations
(4) None of the above.

186. Which of the following remains unchanged in reversible competitive inhibition?
(1) V_{max} (2) K_m
(3) Both (4) None of these

187. What is common among Amylase, rennin and trypsin?
(1) All are proteins
(2) All act at a pH lower than 7
(3) All are proteolytic enzymes
(4) All are produced in stomach

*188. Sulpha drugs/sulphanilamide kill bacteria by inhibiting synthesis of which of the following?
(1) Para-aminobenzoic acid
(2) Folic acid
(3) Phenylalanine (4) Methionin

189. One molecule of an enzyme is needed to convert 2 molecules of a substrate into products in 5 minutes. 10 molecules of the enzyme and 25 molecules of the substrate are mixed in a test tube. After 10 minutes the test tube will be having
(1) products only
(2) products and 5 molecules of unreacted substrate
(3) products, enzyme and 5 molecules of unreacted substrate
(4) products and enzyme

190. ATP was discovered by
(1) Lipmann (2) Karl Lohman
(3) Bowman (4) Blackman

191. Which form of RNA has a structure resembling clover leaf ?
(1) *t*RNA (2) *m*RNA (3) *hn*RNA (4) *r*RNA

192. Enzymes, vitamins and hormones can be classified into a single category of biological chemicals, because all of these
(1) are exclusively synthesized in the body of a living organism as at present
(2) help in regulating metabolism
(3) enhance oxidative metabolism
(4) are conjugated proteins

193. Which one of the following statements regarding enzyme inhibition is correct ?
(1) Competitive inhibition is seen when a substrate competes with an enzyme for binding to an inhibitor protein.
(2) Non-competitive inhibitors often bind to the enzyme irreversibly.
(3) Non-competitive inhibition of an enzyme can be overcome by adding large amount of substrate.
(4) Competitive inhibition is seen when the substrate and the inhibitor compete for the active site on the enzyme

194. The catalytic efficiency of two different enzymes can be compared by the
(1) the pH of optimium value
(2) formation of the product
(3) the K_m value
(4) molecular size of the enzyme

195. Which one is a nucleotide ?
(1) Adenylic acid and guanosine monophosphate
(2) Cytidylic acid and uridine
(3) Uridylic acid and cytosine
(4) All of the above

196. Nucleic acids are strong acids. The acidity is due to
(1) phosphates (2) sugar
(3) nitrogen bases (4) H-bonds

197. Adenylic acid is
(1) Adenine + ribose + phosphate
(2) Adenine + deoxyribose + phosphate
(3) Adenosine + sugar
(4) Adenine + sugar

198. Adenosine monophosphate is a
(1) nucleotide of RNA
(2) nucleoside of RNA
(3) nucleotide of DNA
(4) nucleoside of DNA

199. In DNA model of Watson & Crick, the major grooves are site of
(1) binding of histone proteins
(2) binding of acidic proteins
(3) binding of RNA molecules
(4) binding of glycoproteins

200. At 82-92°C the H–bonds between nitrogen bases of complementary strands of DNA break to uncoil and separate two strands. This is called
(1) denaturation (melting)
(2) renaturation (reannealing)
(3) recombination DNA
(4) DNA finger printing

201. On cooling the two separated strands of DNA again recoil. It is called
(1) chain reaction (2) annealing
(3) both (1) & (2) (4) palindrome

*188. Sulpha drugs compete P-aminobenzoic acid (PABA) which is essential for the synthesis of folic acid in bacteria. The sulpha drugs act as competetive inhibitor and combine with enzyme and do not allow enzyme to act with PABA.

202. If DNA has 10 spirals, the length of DNA will be
(1) 34 Å (2) 340 Å
(3) 640 Å (4) 64 Å

203. What would be the length of DNA containing 10000 base pairs ?
(1) 68000 Å (2) 34000 Å
(3) 10000 Å (4) Im

204. How many nucleotides are found in one spiral of B-DNA ?
(1) 5 (2) 10 (3) 20 (4) 25

205. How many spirals (twins or helices) a DNA of 2000 base pairs will have ?
(1) 2000 (2) 4000 (3) 200 (4) 45.5

206. How many nucleotides will be present in a DNA of 20000 base pairs
(1) 4000 (2) 40000
(3) 20000 (4) 2000

207. RNA differs from DNA in nature of
(1) sugar and purines
(2) sugar and pyrimidines
(3) purines and phosphate
(4) sugar and phosphate

208. A condensation product of nitrogen base and pentose sugar is
(1) nucleotide (2) nucleic acid
(3) nucleoside (4) none of these

209. Nitrogen base is attached to pentose sugar in a nucleoside at carbon atom
(1) 1 (2) 2 (3) 3 (4) 5

210. Basic unit (monomer) of DNA molecule is
(1) nitrogenous base
(2) deoxyribose nucleotide
(3) deoxyribose-nucleoside
(4) pentose sugar

211. In DNA and RNA, pentose sugar has furanose ring. It is
(1) aldose type (2) ketose type
(3) pyranose (4) nonreducing type

212. The bases of RNA are of
(1) 4 types (2) 6 types
(3) 1 type (4) 2 types

213. Which one is covalent bond ?
(1) Peptide bond
(2) Phosphodiester bond
(3) Both correct (4) Both wrong

214. DNA was discovered by
(1) Miescher (2) Altman
(3) Watson (4) Wilkins

215. A molecule of ATP is structurally most similar to a molecule of
(1) RNA nucleotide (2) DNA nucleotide
(3) Amino acid (4) RNA nucleoside

216. Adenosine is
(1) nucleoside (2) nucleotide
(3) a purine (4) a pyrimidine

217. Thymine differs from Uracil in having
(1) CH_3 group (2) $C=O$ group
(3) CHO group (4) COOH group

218. The difference in deoxyribose and ribose sugar is in the
(1) first carbon (2) second carbon
(3) 4th carbon (4) 5th carbon

219. In purines, N is at position ________ in its two rings.
(1) 1,3,7,9 (2) 1,5 (3) 7,9 (4) 1 & 9

220. In pyrimidines, N is at ________ position in its one ring.
(1) 1,3 (2) 7,9 (3) 1 (4) 1 & 6

221. Similarity of RNA and DNA is that both
(1) are double-stranded
(2) have similar sugars
(3) are polymers of nucleotides
(4) have similar pyrimidines

222. Two strands of a molecule of DNA are linked sidewise by
(1) ester bonds (2) glycosidic bonds
(3) purine-pyrimidine hydrogen bonds
(4) all the above

223. The smallest type of RNA is
(1) tRNA (2) mRNA
(3) rRNA (3) genetic RNA

224. In double helix of DNA, the two DNA strands are
(1) coiled upon itself around a common axis
(2) coiled around each other
(3) coiled differently
(4) coiled over protein sheath

225. The type of RNA responsible for proper sequence of amino acids in protein synthesis is
(1) rRNA (2) tRNA
(3) mRNA (4) hnRNA

226. Which of the following RNAs have clover leaf structure ?

(1) transfer RNA (2) messenger RNA
(3) ribosomal RNA (4) heterogenous RNA

227. DNA strands are termed antiparallel because of
(1) H —bonds
(2) phospho-diester bonds
(3) disulphide (S –S bonds)
(4) none of the above

228. In double helix model of DNA how far is each base pair from next ?
(1) 0.034 nm (2) 3.4 nm
(3) 0.34 nm (4) 34 nm

229. The base sequence for a nucleic acid segment is given as GAG AGG GGA CCA. From this it can be concluded that it is a segment of a
(1) DNA strand (2) mRNA strand
(2) tRNA strand (4) Data insufficient

230. Which is correct sequence according to increasing molecular weight ?
(1) tRNA – DNA – rRNA
(2) tRNA – rRNA – DNA
(3) rRNA – DNA – tRNA
(4) DNA – tRNA – rRNA

231. The area of DNA rich in A – T base pairs is called
(1) high melting area
(2) low melting area
(3) microsatellite (4) pallindrome

232. Purines of RNA are
(1) guanine & adenine
(2) uracil & thymine
(3) adenine & cytosine
(4) uracil & guanine

233. Deoxyribose sugar in DNA is
(1) $C_5H_{10}O_5$ (2) $C_5H_{10}O_4$
(3) $C_6H_{12}O_6$ (4) $C_6H_{14}O_5$

234. The double stranded helical structure of DNA is maintained by
(1) amide bonds (2) H—bonds
(3) covalent bonds
(4) phosphodiester bonds

*235. If A = 120 and C = 120, then a piece of DNA will have........ nucleotides.
(1) 240 (2) 280
(3) 480 (4) data insufficient

*236. In *E. coli* DNA has 18% of bases of cytosine What will be the fraction of adenine ?
(1) 18% (2) 32%
(3) 36% (4) data insufficient

237. In 'B' model of DNA, the diameter is 20Å. It is........ in Z DNA
(1) 23Å (2) 18Å (3) 21Å (4) 26Å

238. Which statement is wrong about DNA ?
(1) Some viruses have ssDNA
(2) Some viruses have dsRNA
(3) 'Z' DNA has 12 base pairs per helix
(4) Length of one helix in 'B' DNA is 45Å and 'Z' DNA is 34Å

239. The helical model for DNA given by Watson and Crick was
(1) B type right handed
(2) Z type left handed
(3) B type left handed
(4) Z type right handed

240. Which one of the following ratios is variable but constant for a species ?
(1) $\frac{[A+T]}{[G+C]}$ (2) $\frac{[A+G]}{[T+C]}$
(3) $\frac{[A+U]}{[G+C]}$ (4) None of these

241. If one chain of a DNA molecule has the base order 5' ATTGACGT3' ....then the base order of its complementary chain will be
(1) 3' ATTGACGT 5'
(2) 5' TGCAGTTA 3'
(3) 5' TUUCTGCU 3'
(4) 3' TAACTGCA 5'

242. Amino acid is carried by tRNA at its
(1) 5' end where OH is present
(2) 3' end where OH is present
(3) recognition site (4) loop I

243. Which is recognition site of tRNA ?
(1) Anticodon (2) Loop I
(3) Loop IV (4) 5'–OH end

244. tRNA is attached to mRNA by its
(1) I loop (2) II loop
(3) III loop (4) IV loop

*235. A = T and G = C and, therefore, the given DNA will have 120+120+120+120 = 480 nucleotides.
*236. C = 18%, As C = G and therefore, G = 18%, C+G = 18+18 = 36%, A+T = C + G and therefore, A + T = 100 – 36 = 64% and A = T and thus A = 64/2 = 32%.

245. The ribosomal binding loop of tRNA is
(1) DHU loop (2) anticodon loop
(3) T ψ, C loop (4) III loop

246. RNA is synthesized on
(1) both strands of DNA
(2) on sense strand of DNA
(3) on anti sense strand of DNA
(4) on cDNA

247. Which one of the following has minimum life span ?
(1) mRNA (2) rRNA
(3) tRNA (4) DNA

248. Which one of the following is not given by Erwin Chargaff ?
(1) Base composition of DNA varies from one species to another
(2) The base composition of DNA does not change with age, nutrition or changes in the environment
(3) Molar amounts of adenine are equal to the molar amounts of thymine
(4) DNA can transcribe RNA

249. Genetic information in a DNA molecule is coded in the
(1) sequence of nucleotides
(2) base pairing
(3) turning pattern of helix
(4) distance between base pairs

250. The two polynucleotide chains of DNA are complementary, means
(1) if one starts with 5' end the other must start with 3' end
(2) if the sequence of bases of one chain is known, that of other can be determined
(3) two chains are held up by hydrogen bonds
(4) all of the above

251. Circular DNA is present in
(1) E.R. and ribosomes
(2) ribosomes and chloroplasts
(3) ribosomes and mitochondria
(4) mitochondria and chloroplastis

252. Which of the following is a double ringed structure ?
(1) Guanine (2) Uracil
(3) Thymine (4) Cytosine

253. In a 3.2 kbp long piece of DNA, 820 adenine bases were found. What would be the number of cytosine bases?
(1) 1560 (2) 1480 (3) 780 (4) 740

*254. Match the following
(1) Abrin - (P) Anti-cancer drug
(2) Vinblastin - (Q) Alkaloid
(3) Gums - (R) Toxin
(4) Morphine - (S) Protein
(5) GLUT- 4 - (T) Polymeric Secondary metabolite
(1) (1)-(R); (2)-(P); (3)-(T); (4)-(Q); (5)-(S)
(2) (1)-(P); (2) -(R); (3) -(T); (4) - (Q); (5)- (S)
(3) (1)-(R); (2)-(P); (3)-(Q); (4) – (T); (5)- (S)
(4) (1)-(Q); (2)-(T); (3)-(P); (4) – (R); (5)- (S)

*255. Go through the following statements
(i) In proteins, right handed and left handed helices are observed
(ii) In B-DNA, at each step of ascent, the strand turns 36°.
(iii) Living process is a steady - state in equilibrium.
(iv) The rate of reaction doubles or decreases by half for every 10° C change in either direction.

Find out the correct statement ?
(1) (i), (iii) & (iv) (2) (ii) & (iv)
(3) (i) & (iv) (4) All are correct

*256. Go through the following statements
(i) Lipids are not strictly macromolecules.
(ii) In a polysaccharide chain, the right end is called the non-reducing end and the left end is called the reducing end.
(iii) Cellulose contains complex helices and hence cannot hold I_2.
(iv) Collagen is the most abundant protein in animal world and RUBISCO is the most abundant protein in the whole of the biosphere.

*254. Abrin, Vinblastin, Gums & Morphine are secondary metabolites. GLUT- 4 is a protein that enables glucose transport in to cells.
*255. In proteins, only right handed helices are observed. Systems at equilibrium cannot perform work. As living organisms work continuously, they cannot afford to reach equilibrium. Hence the living state is a non-equilibrium steady-state to be able to perform work.
*256. In polysaccharide chain, right end is the reducing end and the left end is the non-reducing end. Cellulose does not contain complex helices and hence cannot hold I_2.

Find out the correct statements

(1) (i), (ii) & (iii) (2) (ii), (iii) & (iv)
(3) (i), (ii) & (iv) (4) (i) & (iv)

257. Match the following

(1) Valine	(A) Aromatci essential amino acid
(2) Tyrosine	(B) Fatty acid with 20 carbon atoms
(3) Arachidonic acid	(C) Neutral amino acid
(4) Lysine	(D) Fatty acid with 16 carbon atoms
(5) Palmitic acid	(E) Aromatic amino acid
	(F) Basic amino acid

(1) (1) -(E); (2)-(C); (3)- (B); (4) - (F); (5)- (D)
(2) (1) - (E); (2)-(A); (3)- (D); (4) - (F); (5)- (B)
(3) (1) - (C); (2)-(A); (3)-(B); (4) - (F); (5)- (D)
(4) (1) -(C); (2)-(E); (3)-(B); (4) - (F); (5)- (D)

*258. Given below is a comparison of elements present in non-living and living matter. Which of these is incorrect:

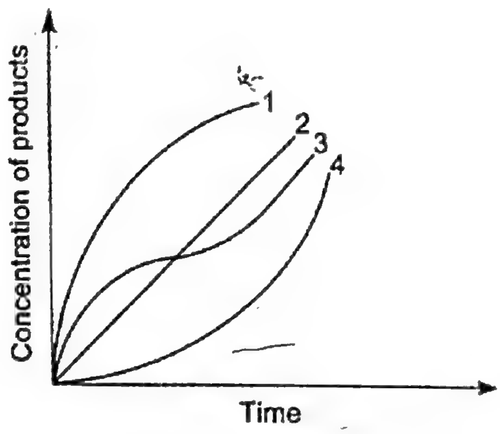
Element	% weight of Earth's crust	% weight of Human body
(1) Silicon	27.7	Negligible
(2) Carbon	0.03	18.5
(3) Calcium	10	5
(4) Nitrogen	Very little	3.3

259. All the following statements describing lipids are true except:
(1) Oxygen content may be more than carbon and hydrogen
(2) They are poorly soluble in water
(3) They are structural components of membranes
(4) They are intracellular energy source

260. Which of the following is the fastest enzyme?
(1) Zymase
(2) Carbonic anhydrase
(3) Amylase
(4) Hexokinase

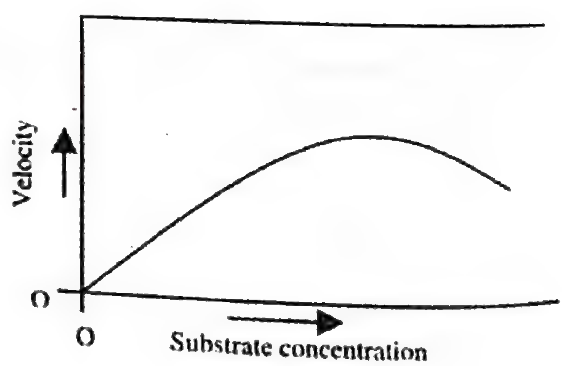
261. Select out the correct sequence according to increase in complexity
(1) Maltose, Fructose, Triose, Oligosaccharide, Starch
(2) Fructose, Maltose, Triose, Starch, Oligosaccharide
(3) Fructose, Maltose, Triose, Oligosaccharide, Starch
(4) Fructose, Maltose, Oligosaccharide, Starch

262. If the rate of a reaction is given as K[A^-] [XB], where [A^-] and [XB] are the concentrations of reactions and if the temperature remains constant, which of the following curves represents the correct variation of reaction rate with time?



(1) 1 (2) 2
(3) 3 (4) 4

263. The graph given below shows the effect of substrate concentration on the rate of reaction of the enzyme green-gram-phosphatase.



What does the graph indicate?
(1) The rate of enzyme reaction is directly proportional to the substrate concentration
(2) Presence of an enzyme inhibitor in the reaction mixture
(3) Formation of an enzyme-substrate complex
(4) At higher substrate concentration the pH increases

*258. Calcium is about 3.6 % in Earth's crust and 1.5% in human body

264. The bonds between the enzyme and substrate must be
(1) Weak and long-lived
(2) Weak and short-lived
(3) Strong and long-lived
(4) Strong and short-lived

265. Consider the following fatty acids
1. Linolenic acid 2. Oleic acid
3. Palmitic acid 4. Stearic acid

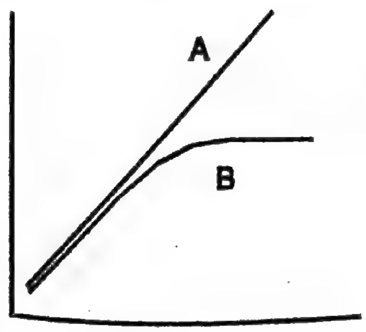
Which of these is/are unsaturated fatty acids?
(1) 1 only (2) 1 and 2
(3) 3 and 4 (4) 2, 3 and 4

266. Consider the following statement
D-glucose, D-galactose and D-fructose are all
1. Isomers 2. Epimers
3. Aldohexoses 4. Monosaccharides

Which of the above statement are correct?
(1) 1 and 4 (2) 2 and 4
(3) 1, 2 and 3 (4) 1, 2 and 4

267. Which one of the following statements is not correct?
(1) All fatty acids have a carboxyl group at one end
(2) Like carbohydrates, fatty acids have more oxygen than hydrogen
(3) Saturated fatty acids are solids at room temperature
(4) Glycerol is a component of phospho lipids

268. The same enzyme catalyzed reaction showed two different kinetic patterns as shown in the graph. Y-axis indicates product formed and X-axis indicates time. Mark the correct interpretation.



(1) Reaction A is carried out at higher temperature than B
(2) Reaction B is carried out at a pH higher than that for reaction A.
(3) Substrate is replenished from time to time in reaction A and not in B
(4) Only reaction A is carried out at optimum ion concentration

269. Listed below are certain proteins. Which of them are the only structural proteins?
(i) Collagen (ii) Trypsin
(iii) Keratin (iv) Actin
(v) Albumin (vi) Tubulin

(1) (i), (iii), (vi) (2) (ii), (iv), (v), (vi)
(3) (i), (iii), (iv), (vi)
(4) (i), (iii), (iv), (v), (vi)

270. Which of the following amino acids have side chain that are negatively charged under physiological conditions?
(1) Aspartic acid (2) Histidine
(3) Tyrosine (4) Serine

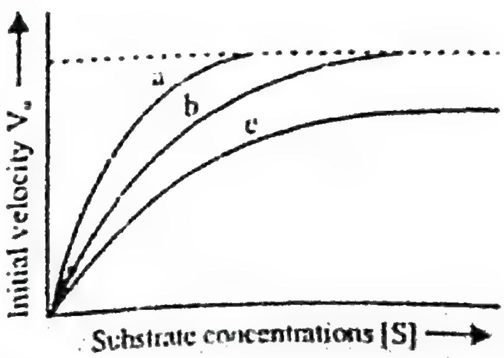
271. When the following amino acids are separated by running them on Agarose gel at *p*H-7, which one of them will migrate slowest to anode end?
(1) Aspartic acid (2) Valine
(3) Glycine (4) Lysine

272. Atherogenic lipoproteins are all EXCEPT
(1) LDL (2) HDL
(3) VLDL (4) Chylomicrons

273. An enzyme that can stimulate germination of barley seeds is
(1) protease (2) invertase
(3) α-amylase (4) lipase

274. An organic substance bound to an enzyme and essential for its activity is called
(1) apoenzyme (2) isoenzyme
(3) coenzyme (4) holoenzyme

275. The figure given below shows three velocity - substrate concentration curves for an enzyme reaction. What do the curves a, b and c depict respectively ?



(1) a-normal enzyme reaction, b-competitive inhibition, c-non-competitive inhibition
(2) a-enzyme with an allosteric modulator added, b-normal enzyme activity, c-competitive inhibition
(3) a-enzyme with an allosteric stimulator, b-competitive inhibition added, c-normal enzyme reaction
(4) a-normal enzyme reaction, b-non-copetitive inhibitor added, c-allosteric inhibitior added

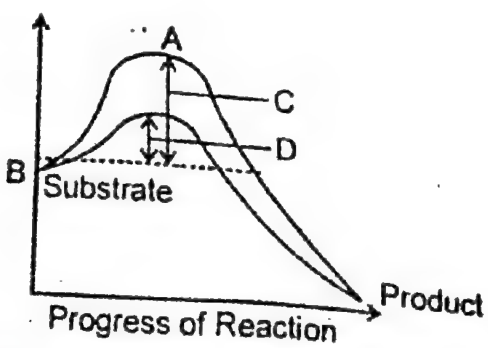
*276. Purines are generally abbreviated as
(1) R (2) Y (3) C (4) U
(Chandigarh CET 2010)

277. Quaternary structure is present in
(1) Histone (2) Haemoglobin
(3) Globulin (4) Elastin *(HP PMT 2010)*

278. Inulin is a polymer of
(1) Amino acids (2) Glucose
(3) Fructose (4) None of the above
(HP PMT 2010)

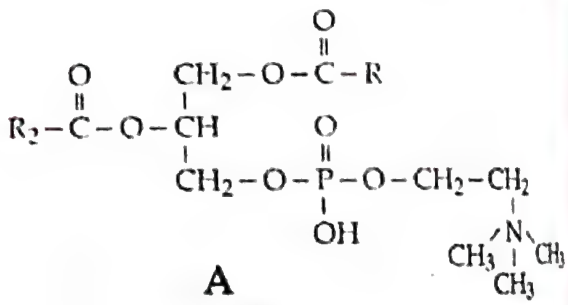
279. Three of the following statements about enzymes are correct and one is wrong. Which one is wrong?
(1) Enzymes require optimum pH for maximal activity.
(2) Enzymes are denatured at high temperature but in certain exceptional organisms they are effective even at temperatures 80° – 90°C
(3) Enzymes are highly specific
(4) Most enzymes are proteins but some are lipids
(CBSE Main PMT 2010)

280. The figure given below shows the conversion of a substrate into product by an enzyme. In which one of the four options (a-d) the components of reaction labelled as A, B, C and D are identified correctly?

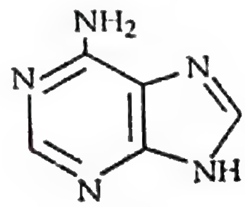


(1) A–Potential energy; B–Transitionstate; C– Activation energy with enzyme; D– Activation energy without enzyme
(2) A– Transition state; B– Potential energy; C–Activation energy without enzyme D– Activation energy with enzyme
(3) A– Potential energy; B– Transition state; C– Activation energy with enzyme; D– Activation energy without enzyme
(4) A – Activation energy with enzyme; B–Transition state; C– Activation energy without enzyme ; D– Potential energy
(CBSE Main PMT 2010)

281. Which one of the following structural formulae of two organic compounds is correctly identified along with its related function?



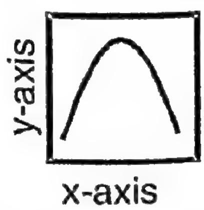
A



B

(1) B : Adenine – a nucleotide that makes up nucleic acids
(2) A : Triglyceride– major source of energy
(3) B : Uracil – a component of DNA
(4) A : Lecithin – a component of cell membrane
(CBSE Prelims 2011)

282. The curve below shows enzymatic activity in relation to three conditions (pH, temperature and substrate concentration).



What do the two axises (x and y) represent?

*276. As per recent IUB nomenclature, unspecified purines are abbreviated as R and unspecified pyrimidines as Y.

x-axis	y-axis
(1) enzymatic activity	pH
(2) temperature	enzyme activity
(3) substrate concentration	enzymatic activity
(4) enzymatic activity	temperature

(AIPMT (Pre.) 2011)

283. Select the type of enzyme involved in the following reaction :

$$\boxed{S-G+S' \rightarrow S+S'-G}$$

(1) dehydrogenase (2) transferase
(3) hydrolase (4) lyase
(5) isomerase

(Kerala PMT 2011)

284. The most abundant RNA in the cell is
(1) rRNA (2) mRNA
(3) tRNA (4) snRNA

(Chandigarh CET 2011)

285. For its activity, carboxypeptidase requires
(1) Niacin (2) Copper
(3) Zinc (4) Iron

(CBSE Main PMT 2012)

286. Which one of the following biomolecules is correctly characterised?
(1) Adenylic acid – adenosine with a glucose phosphate molecule
(2) Alanine amino acid – Contains an amino group and an acidic group anywhere in the molecule
(3) Lecithin – a phosphorylated glyceride found in cell membrane
(4) Palmitic acid – an unsaturated fatty acid with 18 carbon atoms

(CBSE PMT 2012)

287. Which one out of A – D given below correctly represents the structural formula of the basic amino acid?

A	B	C	D
NH_2 H–C–COOH CH_2 CH_2 C(=O)OH	NH_2 H–C–COOH CH_2 OH	CH_2OH CH_2 CH_2 NH_2	NH_2 H–C–COOH CH_2 CH_2 CH_2 CH_2 NH_2

(1) D (2) A (3) B (4) C

(CBSE Prelims 2012)

288. Which one is the most abundant protein in the animal world?
(1) Haemoglobin (2) Collagen
(3) Insulin (4) Trypsin

(CBSE Prelims 2012)

289. Macro molecule chitin is
(1) Sulphur containing polysaccharide
(2) simple polysaccharide
(3) nitrogen containing polysaccharide
(4) phosphorus containing polysaccharide

(NEET 2013)

290. A phosphoglyceride is always made up of
(1) a saturated or unsaturated fatty acid esterified to a glycerol molecule to which a phosphate group is also attached
(2) a saturated or unsaturated fatty acid esterified to a phosphate group which is also attached to a glycerol molecule
(3) only a saturated fatty acid esterified to a glycerol molecule to which a phosphate group is also attached
(4) only an unsaturated fatty acid esterified to a glycerol molecule to which a phosphate group is also attached

(NEET 2013)

291. Transition state structure of the substrate formed during an enzymatic reaction is
(1) transient and unstable
(2) permanent and stable
(3) transient but stable
(4) permanent but unstable

(NEET 2013)

292. Which one of the following is a non-reducing carbohydrate?
(1) Ribose 5-phosphate (2) Maltose
(3) Sucrose (4) Lactose

(AIPMT 2014)

*293. Select the option which is not correct with respect to enzyme action
(1) Malonate is a competitive inhibitor of succinic dehydrogenase
(2) Substrate binds with enzyme at its active site
(3) Addition of lot of succinate does not reverse the inhibition of succinic dehydrogenase by malonate

*293. Inhibition of succinate dehydrogenase by malonate is an example of competitive inhibition, where malonate occupies the active site of the enzyme and blocks it. However, this kind of inhibition is reversible and increase in substrate concentration will reverse this inhibition. In non-competitive inhibition the inhibitor binds to the enzyme at a site different from its substrate binding site (*i.e.*, the active site).

(4) A non-competitive inhibitor binds the enzyme at a site distinct from that which binds the substrate (AIPMT 2014)

294. Which one of the following statements is incorrect?
(1) In competitive inhibition, the inhibitor molecule is not chemically changed by the enzyme
(2) The competitive inhibitor does not affect the rate of breakdown of the enzyme-substrate complex
(3) The presence of the competitive inhibitor decreases the Km of the enzyme for the substrate
(4) A competitive inhibitor reacts reversibly with the enzyme to form an enzyme-inhibitor complex (AIPMT 2015)

295. The chitinous exoskeleton of arthropods is formed by the polymerization of
(1) Keratin sulphate and chondroitin sulphate
(2) D-glucosamine
(3) N-acetyl glucosamine
(4) Lipoglycans (AIPMT Retest 2015)

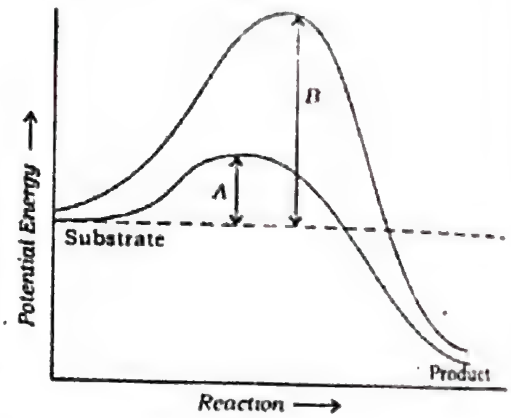
*296. Which of the following biomolecules does have a phosphodiester bond?
(1) Fatty acids in a diglyceride
(2) Monosaccharides in a polysaccharide
(3) Amino acids in a polypeptide
(4) Nucleic acids in a nucleotide (AIPMT Retest 2015)

297. A typical fat molecule is made up of
(1) One glycerol and three fatty acid molecules
(2) One glycerol and one fatty acid molecule
(3) Three glycerol and three fatty acid molecules
(4) Three glycerol molecules and one fatty acid molecule (AIPMT/NEET 2016)

298. Which one of the following statements is wrong?
(1) Cellulose is a polysaccharide
(2) Uracil is a pyrimidine
(3) Glycine is a sulphur containing amino acid
(4) Sucrose is a disaccharide (AIPMT/NEET 2016)

299. Which of the following is the least likely to be involved in stabilizing the three-dimensional folding of most proteins?
(1) Hydrogen bonds
(2) Electrostatic interaction
(3) Hydrophobic interaction
(4) Ester bonds (NEET-2-2016)

300. Which of the following describes the given graph correctly?



(1) Endothermic reaction with energy A in presence of enzyme and B in absence of enzyme
(2) Exothermic reaction with energy A in presence of enzyme and B in absence of enzyme
(3) Endothermic reaction with energy A in absence of enzyme and B in presence of enzyme
(4) Exothermic reaction with energy A in absence of enzyme and B in presence of enzyme (NEET-2-2016)

301. Which one of the following statements is correct, with reference to enzymes?
(1) Apoenzyme = Holoenzyme + Coenzyme
(2) Holoenzyme = Apoenzyme + Coenzyme
(3) Coenzyme = Apoenzyme + Holoenzyme
(4) Holoenzyme = Coenzyme + Co-factor (NEET 2017)

302. Which of the following are not polymeric ?
(1) Nucleic acids (2) Proteins
(3) Polysaccharides (4) Lipids (NEET 2017)

303. Which of the following RNAs should be most abundant in animal cell?
(1) r-RNA (2) t-RNA
(3) m-RNA (4) mi-RNA (NEET 2017)

*296. Although the best answer is option (4), but this option doesn't make any sense, it should have been "Nucleotides in a Nucleic acid".

ANSWERS

1. (1)	2. (1)	3. (1)	4. (3)	5. (1)	6. (1)	7. (2)	8. (1)	9. (2)	10. (4)
11. (1)	12. (2)	13. (4)	14. (3)	15. (4)	16. (3)	17. (3)	18. (1)	19. (4)	20. (2)
21. (4)	22. (3)	23. (1)	24. (3)	25. (1)	26. (2)	27. (2)	28. (1)	29. (1)	30. (1)
31. (3)	32. (2)	33. (3)	34. (1)	35. (4)	36. (1)	37. (2)	38. (1)	39. (2)	40. (1)
41. (1)	42. (2)	43. (2)	44. (1)	45. (3)	46. (1)	47. (4)	48. (3)	49. (4)	50. (1)
51. (2)	52. (1)	53. (3)	54. (3)	55. (3)	56. (1)	57. (2)	58. (3)	59. (2)	60. (1)
61. (1)	62. (1)	63. (4)	64. (1)	65. (4)	66. (2)	67. (1)	68. (2)	69. (2)	70. (2)
71. (3)	72. (3)	73. (4)	74. (4)	75. (1)	76. (1)	77. (4)	78. (2)	79. (3)	80. (4)
81. (4)	82. (4)	83. (3)	84. (4)	85. (1)	86. (3)	87. (3)	88. (1)	89. (2)	90. (4)
91. (1)	92. (1)	93. (1)	94. (1)	95. (3)	96. (2)	97. (2)	98. (3)	99. (3)	100. (3)
101. (3)	102. (2)	103. (3)	104. (1)	105. (1)	106. (3)	107. (1)	108. (2)	109. (4)	110. (3)
111. (2)	112. (1)	113. (2)	114. (4)	115. (1)	116. (2)	117. (1)	118. (3)	119. (1)	120. (3)
121. (2)	122. (1)	123. (1)	124. (4)	125. (3)	126. (2)	127. (1)	128. (4)	129. (2)	130. (1)
131. (1)	132. (1)	133. (3)	134. (4)	135. (3)	136. (1)	137. (4)	138. (2)	139. (4)	140. (3)
141. (3)	142. (2)	143. (1)	144. (3)	145. (3)	146. (1)	147. (1)	148. (1)	149. (2)	150. (2)
151. (4)	152. (2)	153. (1)	154. (1)	155. (2)	156. (1)	157. (2)	158. (3)	159. (1)	160. (1)
161. (1)	162. (1)	163. (1)	164. (2)	165. (3)	166. (1)	167. (1)	168. (1)	169. (3)	170. (1)
171. (2)	172. (2)	173. (2)	174. (1)	175. (2)	176. (1)	177. (4)	178. (1)	179. (4)	180. (1)
181. (1)	182. (4)	183. (4)	184. (1)	185. (2)	186. (1)	187. (1)	188. (2)	189. (4)	190. (2)
191. (1)	192. (2)	193. (4)	194. (3)	195. (1)	196. (1)	197. (1)	198. (1)	199. (2)	200. (1)
201. (2)	202. (2)	203. (2)	204. (3)	205. (3)	206. (2)	207. (2)	208. (3)	209. (1)	210. (2)
211. (1)	212. (1)	213. (3)	214. (1)	215. (1)	216. (1)	217. (1)	218. (2)	219. (1)	220. (1)
221. (3)	222. (3)	223. (1)	224. (1)	225. (3)	226. (1)	227. (2)	228. (3)	229. (4)	230. (2)
231. (2)	232. (1)	233. (2)	234. (2)	235. (3)	236. (2)	237. (2)	238. (4)	239. (1)	240. (1)
241. (4)	242. (2)	243. (1)	244. (2)	245. (3)	246. (3)	247. (1)	248. (4)	249. (1)	250. (2)
251. (4)	252. (1)	253. (3)	254. (1)	255. (2)	256. (4).	257. (4)	258. (3)	259. (1)	260. (2)
261. (4)	262. (1)	263. (2)	264. (2)	265. (2)	266. (1)	267. (2)	268. (3)	269. (3)	270. (1)
271. (4)	272. (2)	273. (3)	274. (3)	275. (1)	276. (1)	277. (2)	278. (3)	279. (4)	280. (2)
281. (4)	282. (2)	283. (2)	284. (1)	285. (3)	286. (3)	287. (1)	288. (2)	289. (3)	290. (1)
291. (1)	292. (3)	293. (3)	294. (3)	295. (3)	296. (4)	297. (1)	298. (3)	299. (4)	300. (2)
301. (2)	302. (4)	303. (1)							

10 CELL CYCLE AND CELL DIVISION

Rudolf Virchow (1855, 1859) was the first to suggest that new cells are formed from the division of the pre-existing cells— *omnis cellula e cellula* (every cell is derived from a cell). In 1873, Strasburger similarly proposed that nuclei are formed from pre-existing ones. Boveri (1879) and Flemming (1879,1880) studied details of somatic cell division. Flemming (1882) coined the term of **mitosis** for it. Van Benedin (1887), Strasburger (1888), Sutton (1900) and Winiwater (1900) studied the details of division that occur prior to the formation of gametes. They found that chromosome number is reduced to half in gametes as compared to their parent cells. The division was termed as **meiosis** by Farmer and Moore (1905).

Cell Types

A cell with a single set of chromosomes is known as **haploid** (n). A cell with two sets of chromosomes is called **diploid** (2n). In diploid cell there are two similar chromosomes or **homologous chromosomes** of each type. Nonreproductive body cells of the body are called **somatic cells.** Some of these cells are capable of continuous division. They are called **stem cells** (*e.g.*, bone marrow cells). The cells that form gametes or sex cells are called **reproductive cells.**

Cell Cycle (Fig. 10.1)

Cell cycle (Howard and Pelc, 1953) is a genetically controlled series of changes that occur in a newly formed cell by which it **duplicates** its **genome**, synthesises other constituents, undergoes **growth** and divides to form two daughter cells. *All these events occur in a coordinated manner and are under genetic control.*

Various phases of cell cycle are controlled by proteins **cyclins** and cyclin dependent protein kinases (CDKs). Protein kinases are enzymes that phosphorylate proteins using ATP. The transition from G_1 to S and from G_2 to M is carried by these CDKs. Actually there are two regulatory mechanisms, called **check points** which take decision about cell division (Fig. 10.2). **First check point,** called G_1 cyclin lies in between G_1 and S. In G_1, CDK becomes active by G_1 cyclin and ATP. It causes transition of G_1 to S phase. **Second check point** lies between G_2 and M. It is called mitotic cyclin (C_M). On being activated it causes transition from G_2 to M phase. At the end of M phase, cyclin C_M is degraded and the cell enters G_1 again.

In embryo, meristems and other generative regions, the cells undergo repeated divisions. The time interval between two cell cycles is called **generation time.** Generation time varies from a few minutes to a few days depending upon the type of cell and its environmental conditions. In culture, human cells divide once every 24 hours (10 hrs in G_1, 9 hrs in S, 4hrs in G_2 and 1 hr in M phase). It is 90 minutes in case of yeast and 20 minutes in case of bacteria.

Cell cycle consists of two **basic phases, states** or **periods.** There is a long nondividing growing I-phase and a short-dividing M-phase. Both have substages. M-phase is the period or basic phase of actual cell division. It is of short duration as compared to I-phase. In the average duration of 24 hours in the cell cycle of dividing human cell, M-phase lasts for a mere one hour (less than 5% of total). I-phase represents interphase.

I. Interphase

Interphase (L. *inter*– between, Gk. *phasis*– aspect) *is a series of changes that take place in a newly formed cell and its nucleus before it becomes capable of division again.* Therefore, it is also called **intermitosis**. Previously it was called **resting stage** because there is no apparent activity related to cell division. The interphase cell is metabolically quite active. There is replication of various subcellular components including chromosomes. Cell grows in size and becomes almost double. At the end of interphase the cell becomes ready for equitable division into two equal daughter cells. Some workers term interphase as **energy phase.** Interphase occupies 75–95% of the total generation time. However, the non-dividing state of the mature cell and its nucleus is also called **interphase.** It lasts throughout the life of the cell. Human nerve cells do not divide after birth. Therefore, interphase period of human nerve cells, lasts throughout the life of a person. Interphase of a dividing cell has three stages— G_1, S and G_2.

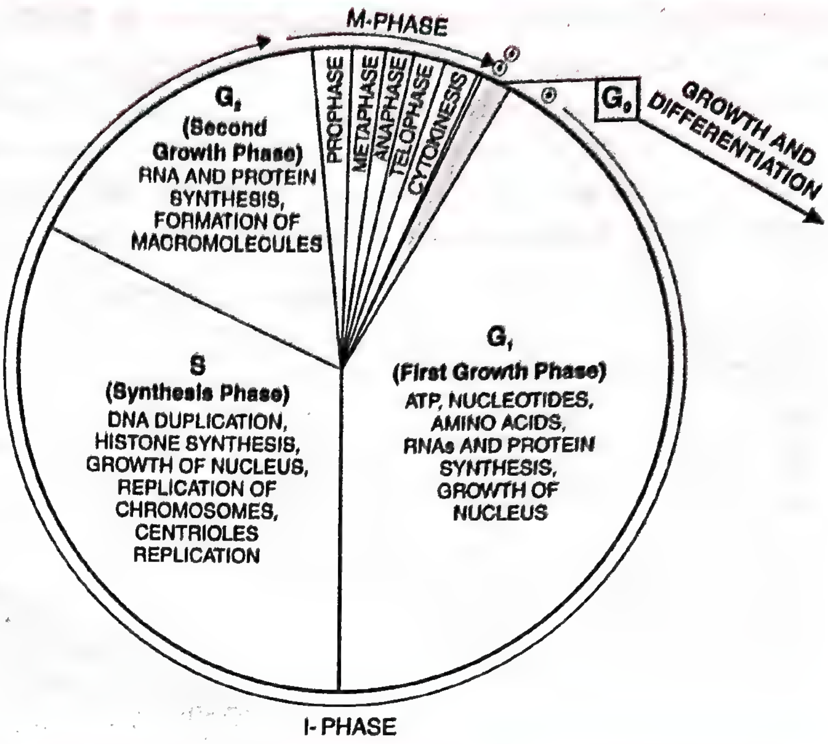


Fig. 10.1 Cell Cycle.

1. **G_1-Phase** (First growth phase or Post mitotic Gap phase). It is phase between end of M-phase of previous cell cycle and initiation of DNA replication. G_1 is the longest phase of interphase. The cell is metabolically active and grows continuously. Nucleus, however, grows only to a small extent. RNA and proteins are synthesised. A large number of nucleotides, amino acids for histone synthesis and energy rich compounds are formed. Cell organelles also increase in number. Duration of G_1 phase is variable. It is longer for cells dividing infrequently. A shorter G_1-phase occurs in cells undergoing frequent divisions. In G_1-phase, a cell has three options. (i) To continue cell cycle and enter S-phase. (ii) Stop cell cycle and enter G_0 phase for undergoing differentiation. (iii) Get arrested in G_1-phase whence it may enter G_0 phase or re-enter cell cycle. The deciding factor is availability of mitogens and storage of energy rich compounds at the deciding point called **check point.** This check point is called G_1 cyclin or C_{G_1}. It causes transition of G_1 to S phase. Once the check point of G_1-phase is crossed, cell cycle will go on uninterrupted till it is completed.

2. **S-Phase.** In S-phase (synthetic phase) the chromosomes replicate. For this their DNA molecules function as templates and form carbon copies. The DNA content doubles *i.e.*, 1C to 2C for haploid cells and 2C to 4C for diploid cells. As a result duplicate sets of genes are formed. Alongwith replication of DNAs, new chromatin fibres are formed which, however, remain attached in pairs and the number of chromosomes does not increase *i.e.*, 1n to 1n and 2n to 2n. As chromatin fibres are elongated chromosomes, each chromosome comes to have two chromatin threads or sister chromatids which remain attached at a common point called **centromere.** S-phase is also called **invisible phase** of M-stage since it is in this phase that the chromosomes prepare themselves for equitable distribution later

on. Subunits of kinetochores are synthesised. Centrosome also begins to divide in centriole containing cells to form two centrosomes or centriole pairs.

3. **G_2-Phase.** In G_2-phase (second growth phase or pre-mitotic gap phase) synthesis of DNA stops. However, formation of RNAs and proteins continues. They are required for multiplication of cell organelles, spindle formation and cell growth. It prepares the cell to undergo division. The second check point called mitotic cyclin (C_M) lies between G_2 and M phase and causes transition from G_2 to M phase.

Differences between G_1 and G_2 Phases

G_1-Phase	*G_2-Phase*
1. It is the first substage of interphase.	1. It is the last substage of interphase.
2. Available factors determine its fate, entry in G_0, differentiation or continuity of cell cycle.	2. There is very little choice for the cell except to proceed further in cell cycle.
3. Cell organelles do not increase in number.	3. Cell organelles increase in number.
4. Cell grows in size but growth of nucleus is little.	4. Both cell and nucleus grow in size.
5. It synthesizes RNAs, proteins and other biochemicals for cell growth and subsequent replication of DNA.	5. It synthesizes RNAs, proteins and other biochemicals for spindle formation and M-phase division.

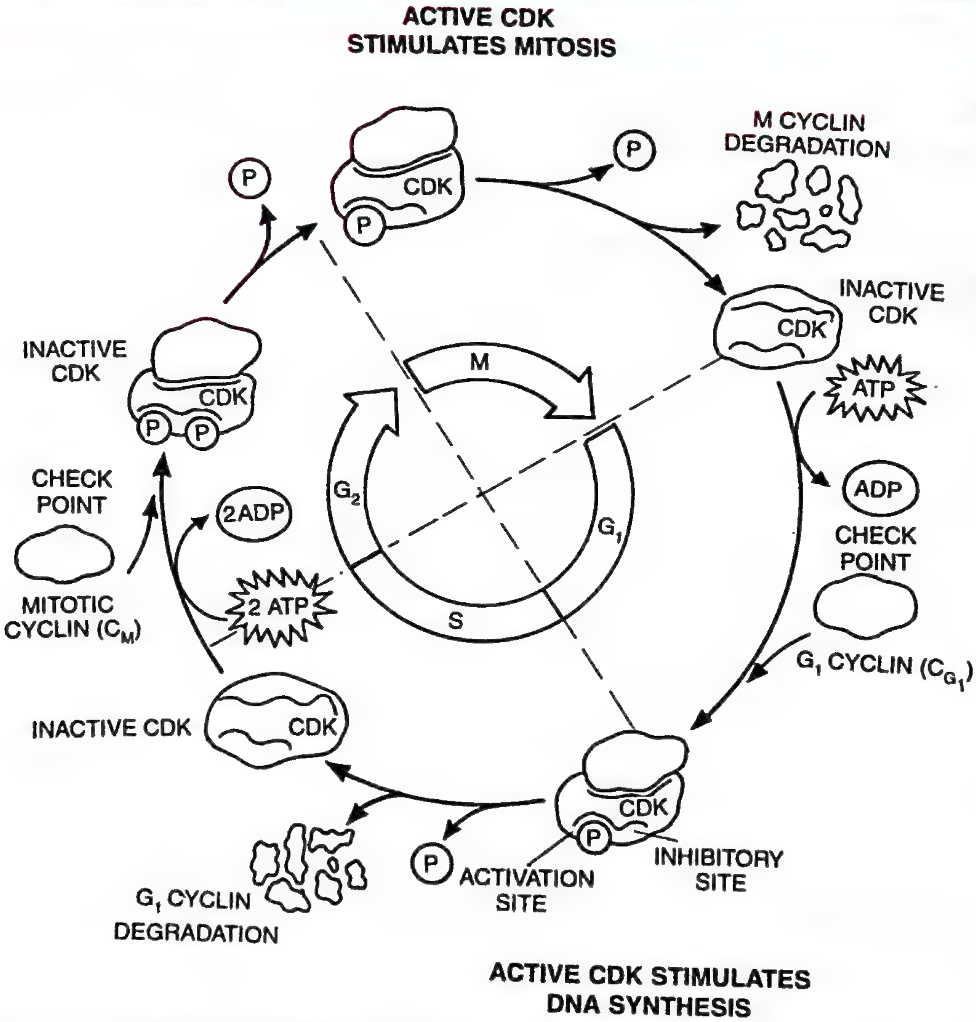


Fig. 10.2. Diagram of the cell cycle showing regulation of the cell cycle by cyclin dependent protein kinase (CDK).

II. Mitotic Phase (M-phase)

M-phase is the final phase of cell cycle. It represents the phase of actual division. Prior to it, the cell components have undergone duplication. M-phase is, therefore, the stage of separation of already duplicated components. It consists of **karyokinesis** (division of nucleus) and **cytokinesis** (division of cell protoplast). After M- phase a cell may re-enter fresh cycle or pass into G_0-phase. G_0-phase (Lajtha, 1963) is the stage when cell cycle is arrested. Therefore, further divisions stop. The cell may then grow in size and become differentiated.

G_0-Phase (Quiescent Stage)

It is the stage of inactivation of cell cycle due to non-availability of mitogens and energy rich compounds. The cells remain metabolically active. They do not grow or differentiate. The cells function as **reserve cells** which can join cell cycle any time. **Differentiation Phase.** Most of the cells leave the G_1-phase midway. They grow in size, assume particular shape and come to have a particular function. The phenomenon is called cell differentiation.

Significance of Cell Division

(i) **Cell Multiplication.** Cell division is a means of cell multiplication or formation of new cells from pre-existing cells. (ii) **Continuity.** It maintains continuity of living matter generation after generation. (iii) **Asexual Reproduction.** Cell division is a means of asexual reproduction in lower organisms. (iv) **Multicellular Organisms.** The body of a multicellular organism is formed of innumerable cells. They are formed by repeated divisions of a single cell or zygote. As the number of cells increases, many of them begin to differentiate, form tissues and organs. In fully formed multicellular individuals, only some of the cells retain the power of division, *e.g.*, bone marrow, germinal tissues, stratum germinativum, meristematic regions (in plants). (v) **Growth.** Growth of an organism involves growth and division of its cells. (vi) **Cell Size.** Cell division helps in maintenance of a particular cell size which is essential for efficiency and control of cell activities. (vii) **Genetic Similarity.** The common type of cell division or mitosis maintains genetic similarity of all the cells in an individual despite their being different structurally and functionally. It is helpful in proper coordination. (viii) **Repair.** Cell division is a means of repair and healing of injured regions of the body. Old or worn out cells are similarly replaced by new ones. (ix) **Regeneraton.** Cell division helps in regeneration of a part or whole of the organism. (x) **Sexual Reproduction.** Sexual reproduction requires a special type of cell division called meiosis. (xi) **Reshuffling of Genetic Traits.** Meiosis is a means of reshuffling of genetic traits. It introduces variability. (xii) **Mutations.** During cell division, there is replication of genetic material. Any change during this activity results in mutations.

Factors Controlling Cell Division

(i) **Cell Size.** Cells capable of division grow for some time, attain a particular size and then undergo division.

(ii) **Kernplasma or Karyoplasmic Ratio.** Rise in cell volume disturbs kernplasma ratio. It stimulates the cell to divide.

Onion cells have 2n chromosomes (2n = 16). In root apical meristem the cells will have 2n chromosomes and 2C DNA content in G_1 phase. At the end of S-phase, the chromosome number remains 2n while DNA content becomes 4C due to replication of DNA and formation of two interconnected chromatids by each chromosome. At the end of G_2 phase there is no change in chromosome number (2n) and DNA content (4C). M-phase results in reducing the DNA content from 4C to 2C but the chromosome number does not change because the replicated chromosomes of S-phase split in M-phase to form two sets of daughter chromosomes, each set going to a daughter cell.

(iii) **Mitogens.** Mitogens are agents, factors or substances that trigger cell division. The common plant mitogen is hormone cytokinin. There are several mitogenic substances known in human beings, *e.g.*, lymphokines, EGF (epidermal growth factor), PDGF (platelet derived growth factor).

CELL DIVISION

Cell division, cell reproduction or cell multiplication is the process of formation of new or daughter cells from the pre-existing or parent cells. It occurs in three ways : amitosis, mitosis and meiosis.

AMITOSIS

It is a simple method of cell division which is also called **direct cell division.** Amitosis was discovered by Remak (1841,1855) and described by Flemming (1882). In this division there is no differentiation of chromosomes and spindle. The nuclear envelope does not degenerate. The nucleus elongates and constricts in the middle to form two daughter nuclei. This is followed by a centripetal constriction of the cytoplasm to form two daughter cells. Amitosis is not a regular method of division because it does not divide the nuclear matter equitably. It occurs in metabolic nucleus (*e.g.*, meganucleus of *Paramecium*) of some protozoa. The growth of embryonic membrane of some vertebrates is due to this type of cell division. Amitosis also occurs in diseased cells. In *Chara*, internodal nuclei divide by amitosis. It is not followed by cytokinesis. This produces a large number of nuclei of unequal size. Some authors include cell division of monerans (*e.g.*, bacteria) under amitosis due to absence of spindle formation. As compared to amitosis, other types of divisions (mitosis and meiosis) are called **indirect cell divisions.**

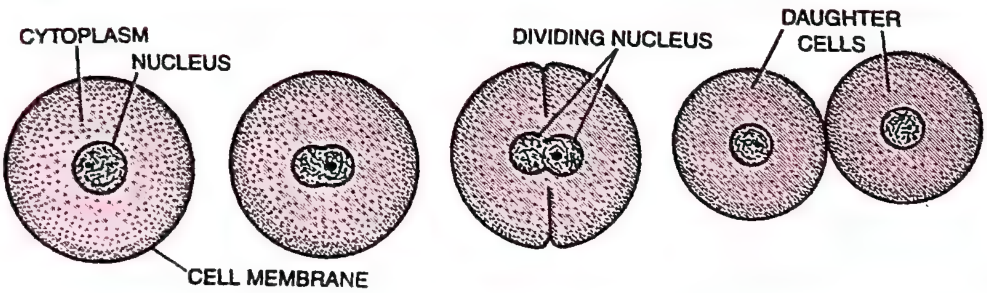


Fig. 10.3. Stages in amitosis.

MITOSIS

Mitosis (Gk. *mitos*– thread or fibril) *is that type of division in which chromosomes replicate and become equally distributed both quantitatively and qualitatively into two daughter nuclei so that the daughter cells come to have the same number and type of chromosomes as are present in the parent cell.* It is, therefore, also called **equational division**. Mitosis was first observed by Strasburger (1870) in plant cells, Boveri and Flemming (1879) in animal cells. The term of mitosis was coined by Flemming (1882). It is the most common method of division which brings about growth in multicellular organisms and increase in population of unicellular organisms. Mitosis occurs in the formation of somatic body cells and is hence often named as **somatic cell division**. The sites of mitotic cell division in a plant are meristematic regions like stem tip, root tip, intercalary meristem, lateral meristem, growth of embryo, leaves, flowers, fruits, seeds, etc. In animals, mitosis is found

in embryo development and some restricted regions in the mature form like skin and bone marrow. It can be easily studied in smears or sections of root and stem tips. While the plant cell does not show much change, the animal cell becomes spheroid, more viscous and refractile at the time of mitosis. Depending upon the type of cell and the species, mitosis takes 30 minutes to 3 hours for completion.

Mitosis consists of two steps— karyokinesis and cytokinesis.

Karyokinesis

Karyokinesis (Gk. *karyon*– nucleus, *kinesis*– movement) is also called **indirect nuclear division** because the nucleus passes through a complicated sequence of events before forming two daughter nuclei. Though the process is continuous one without any pauses, it has been divided into four phases or stages for the sake of convenience depending upon the completion or beginning of a specific event. They are prophase, metaphase, anaphase and telophase. A fifth stage of prometaphase is recognised by some workers.

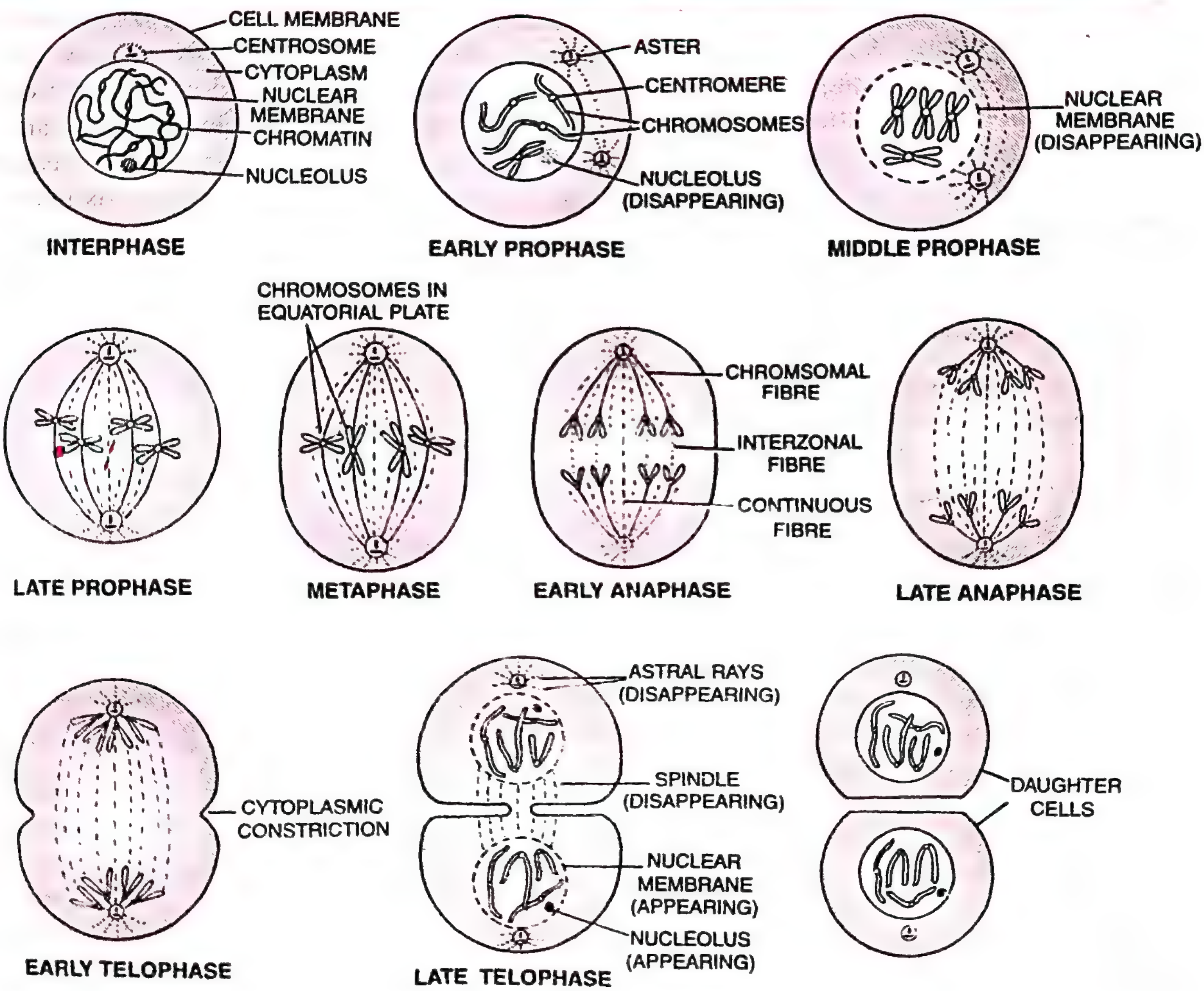


Fig. 10.4. Different stages of mitosis in an animal cell.

1. **Prophase** (Gk. *pro*– first, *phasis*– stage). It is often studied in three substages— early, middle and late. In early prophase, the nucleus becomes spheroidal. Viscosity of

cytoplasm increases. The indistinct and intertwined DNA molecules condense to form elongated chromosomes. Therefore, the chromatin reticulum disappears. The shortening and thickening of chromosome fibres occur due to two reasons : (i) Coming together of scaffolding or axial proteins. (ii) Twisting and coming together of lateral loops of chromatin to form filaments. It is assisted by proteins **condensins** (Kimura *et al*, 1999). The elongated chromosomes may show overlapping. Their ends are not visible. Therefore, the chromosomes appear like a **ball** of wool. It is also called **spireme stage.**

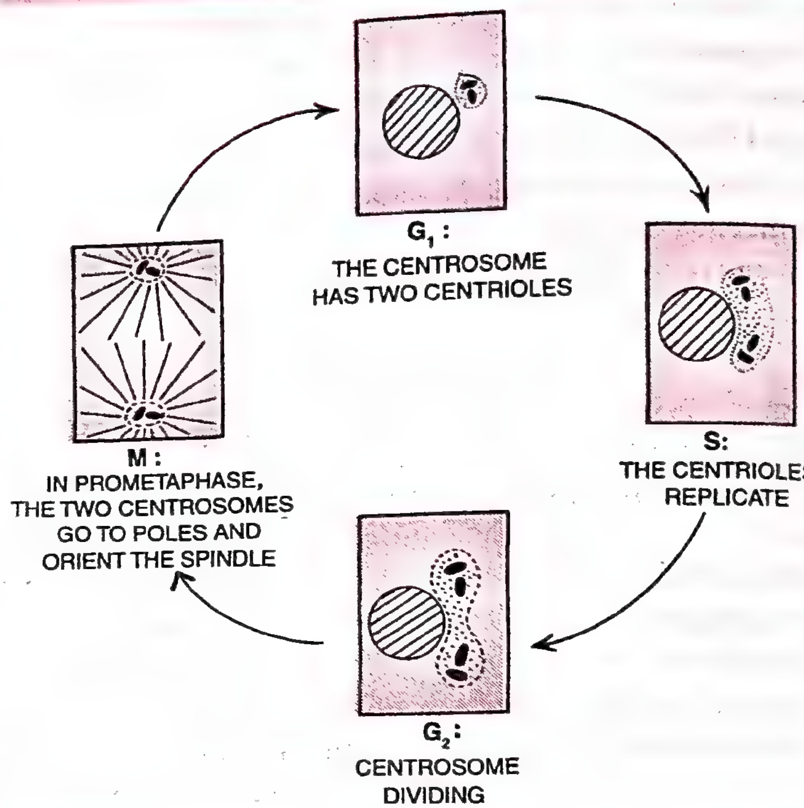


Fig. 10.5. Centrosome cycle during cell cycle.

In the beginning of prophase, animal cells have two centrosomes or centriole pairs close together. The two begin to shift towards the opposite sides. Both the centriole pairs radiate out fine microtubular fibrils called astral rays. Each group of astral rays alongwith its centriole pair is called **aster**. In an aster, the microtubular astral rays are not connected to centrioles but to pericentriolar satellites.

In early prophase, chromosomes are evenly distributed inside nucleus. In **middle prophase** they shift towards the periphery or nuclear envelope so as to leave a clear central area. Simultaneously the chromosomes shorten and thicken further to assume characteristic shape and size. The size of chromosomes is reduced to some 1/25 of their size in early prophase. Shortening of chromosomes is a must for their equitable distribution later during anaphase. Each chromosome appears to consist of two longitudinal threads called **chromatids.** The two chromatids, also called **sister chromatids**, are attached to each other by means of a narrow point called **centromere.** Nucleolus or nucleoli are found attached to one or more chromosomes. They, however, appear smaller as compared to those of interphase nucleus.

In late prophase fine fibres start appearing around the nucleus. The nucleolus or nucleoli degenerate completely. By this time the two asters (centriole pairs and their astral rays) come

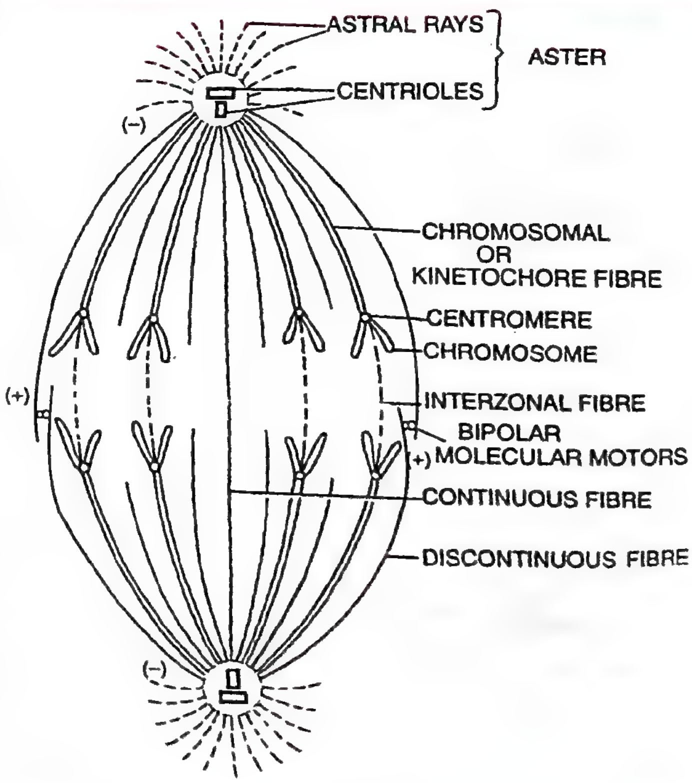


Fig. 10.6. Chromosomes, asters and spindle in mitotic anaphase.

to lie in the area of future spindle poles. Spindle poles are organised without asters in plant cells. The two spindle poles begin to get connected by fine fibres.

Prometaphase (Gk. *pro*– before, *meta*– second, *phasis*– stage). Nuclear envelope degenerates. Differentiation between cytoplasm and nucleoplasm disappears. Endoplasmic reticulum and Golgi complex disorganise Spindle apparatus is fully organised. It is spindle-shaped, colourless or achromatic bipolar fibrous body. Spindle apparatus (mitotic apparatus) consists of numerous fine fibres. Each fibre is actually made up of 4–20 microtubules. The spindle fibres converge towards the two ends called **poles.** In animal cells the poles are formed by asters. Since there are two asters, the spindle of animal cell is called **amphiaster** (Gk. *amphi*– both, *aster*– star). In contrast, the spindle of plant cells is called **anastral** (Gk. *an*– not, *aster*— star). Anastral spindle is also called **acentric** while amphiaster is called **centric spindle.**

The spindle apparatus has the maximum diameter in the middle. The area is called **equator**. The fibres of the spindle, have negative end near the pole and positive end near the middle. Some fibres overlap in the middle, get connected by bipolar molecular motors and form apparent **continuous fibres.** Others are **discontinuous** (which radiate out from one pole but do not reach the other). Chemically the spindle consists of 90–95% proteins (mostly tubulin rich in sulphur containing amino acids with traces of actin and myosin), 3.5–5% RNA and traces of lipids and other substances.

Mitotic division in which nuclear envelope degenerates during organisation of spindle is called **extranuclear mitosis** or **eumitosis**. In many protists, fungi and algae nuclear envelope does not degenerate. Spindle is formed inside the nucleus and mitosis occurs there. It is called **premitosis** or **intranuclear mitosis**. It may be centric or acentric.

With the dissolution of nuclear envelope, the central part of the cell comes to have a clear fluid area. Chromosomes move freely in this area.

2. **Metaphase** (Gk. *meta*– after or second, *phasis*– stage). Discontinuous fibres coming from the two spindle poles get connected to the two centromere surfaces or kinetochores

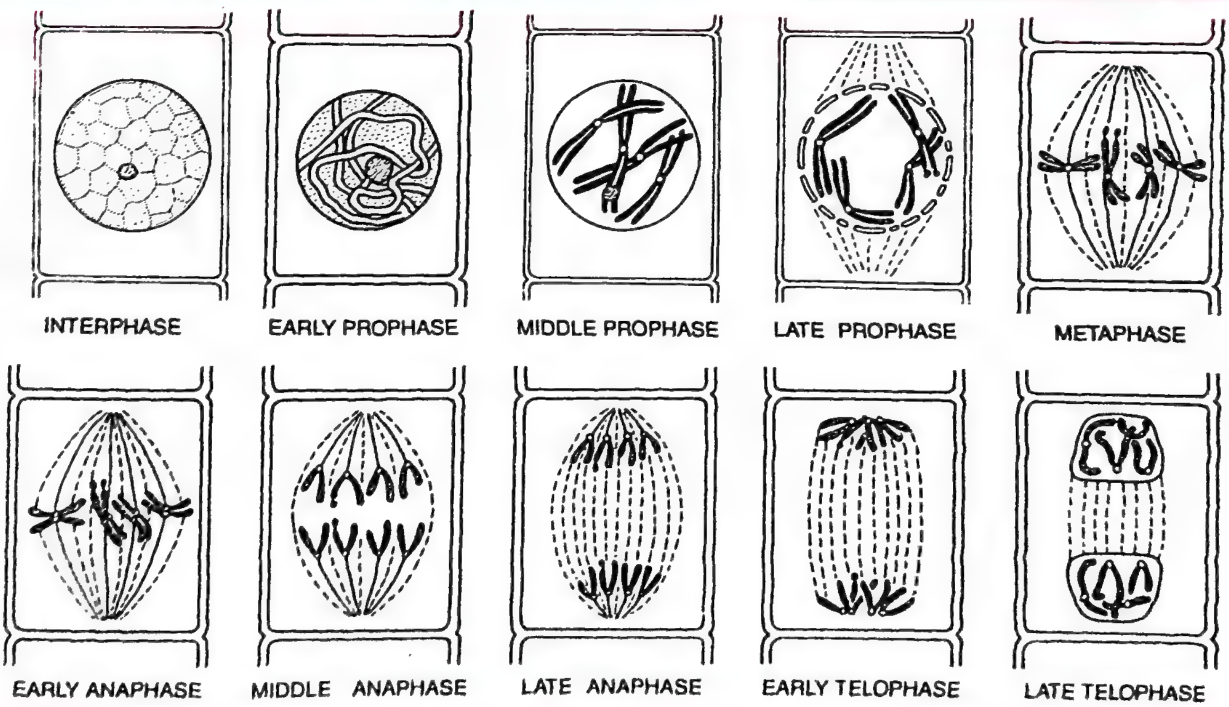


Fig. 10.7. Different stages of mitosis in a plant cell.

of each chromosome by means of corona having molecular motors. They are called **kinetochore fibres** or **chromosome fibres** (or **tractile fibrils**). Each chromosome is attached to both the spindle poles by distinct chromosome fibres, one for each chromatid. Chromosome fibres now tighten. This brings the chromosomes on the equator of the spindle. The phenomenon of bringing the chromosomes on the equator of the spindle is called **congression**. On the equator the small chromosomes come to lie towards the interior while the larger ones are arranged towards the periphery. The centromeres of all the chromosomes lie on the equator while the limbs are placed variously according to their size and spatial arrangement. The centromeres of all the chromosomes form an apparent plate called **metaphasic** or **equatorial plate** (actually they are present in the form of a circle). Metaphase is the best time to count the number and study the morphology of chromosomes.

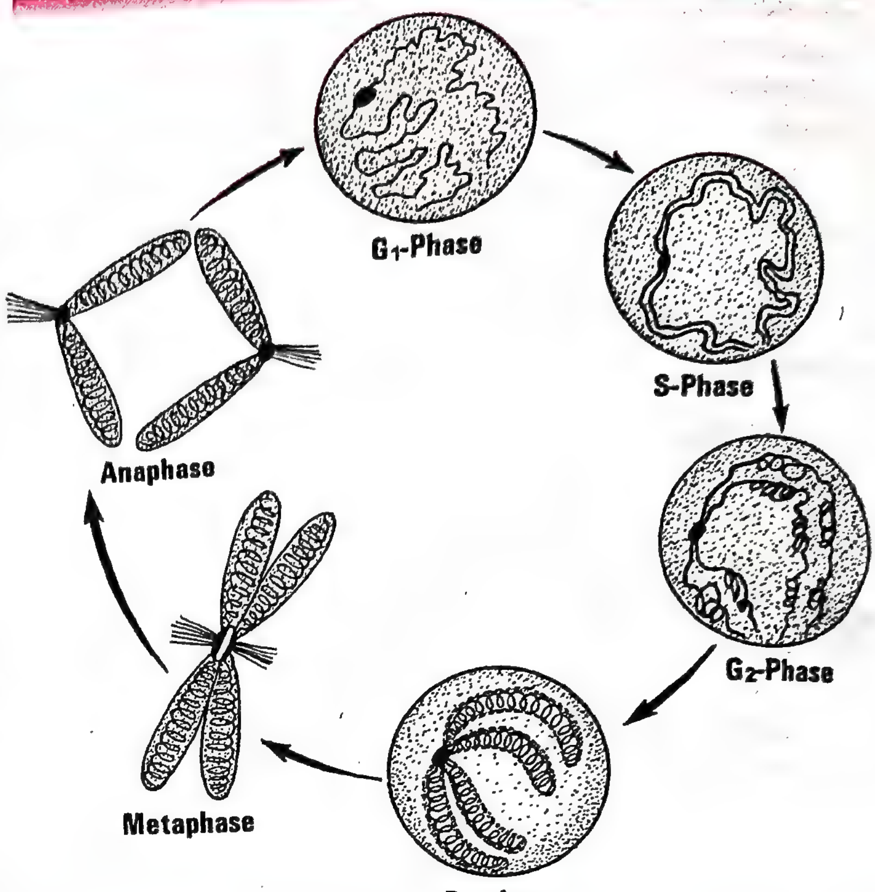


Fig. 10.8. Behaviour of a chromosome during interphase and mitosis.

3. **Anaphase** (Gk. *ana*– up, *phasis*– stage). It has two substages, A and B.

Anaphase A. The centromere of each chromosome divides into two, so that each chromatid comes to have its own centromere. The two chromatids now start repelling each other and separate completely to become daughter chromosomes. The daughter or new chromosomes move towards the poles of spindle along the path of their chromosome fibres or tractile fibrils. They may remain connected to each other by **interzonal fibres.** Simultaneously, the spindle elongates. In anaphasic movement of chromosomes, the centromeres lead the path while the limbs trail behind. As a result the anaphasic chromosomes appear V, L-, J- and I-shaped. The shapes are formed respectively in metacentric, submetacentric, acrocentric and telocentric chromosomes.

Anaphase B. At the end of anaphase two groups of chromosomes are formed, one at each pole of the spindle. The spindle elongates. Most spindle fibres disappear from near the poles but remain intact near the middle. The number and type of chromosomes at each pole is the same as present in the parent nucleus.

Causes of Anaphasic Movement. (i) Each chromosome fibre or tractile fibril consists of microtubules. The spindle is also formed of microtubules. The chromosome may glide over the spindle fibres by (a) molecular motors or (b) under force developed at the poles. (ii) Anaphasic movements are caused by contraction of chromosomes fibres. (iii) Formation and expansion of interzonal fibres. (iv) Dissolution of microtubules of chromosome fibres at their ends assisted by molecular motors.

4. **Telophase** (Gk. *telos*– end, *phasis*– stage). The stage is reverse of prophase. During this phase the cytoplasmic viscosity decreases. The two chromosome groups (formed at the end of anaphase) reorganise themselves into nuclei. The chromosomes elongate and overlap

one another to form chromatin. The nucleolar organiser regions of satellite chromosomes produce nucleoli which may or may not fuse. Nucleoplasm collects in the area of chromatin. A nuclear envelope appears on its outside from pieces of older nuclear envelope and annulated endoplasmic reticulum. In this way two daughter nuclei are formed at the poles of the spindle.

In the telophase the spindle fibres disappear around the poles. Golgi complex and endoplasmic reticulum are reformed. In animal cells the astral rays are also withdrawn. Rest of the spindle fibres persist during the cell plate method of cytokinesis but disappear where cytokinesis takes place by cleavage or constriction.

Cytokinesis (D-Phase)

Cytokinesis (Gk. *kytos*– hollow or cell, *kinesis*– movement) is the division of protoplast of a cell into two daughter cells after the nuclear division or karyokinesis, so that each daughter cell comes to have its own nucleus. Cell organelles (mitochondria, plastids, Golgi bodies, lysosomes, endoplasmic reticulum, ribosomes) are also distributed between the two daughter cells. Mitochondria and plastids undergo division by cleavage or fission. Details of replication of other organelles are not known. At times, cytokinesis does not follow karyokinesis. It produces multinucleate condition known as **coenocyte** or **syncytium**. Normally, cytokinesis starts towards the middle anaphase and is completed simultaneously with the telophase. Cytokinesis is different in animal and plant cells.

Differences between Karyokinesis and Cytokinesis

Karyokinesis	*Cytokinesis*
1. It is division of nucleus into two daughter nuclei.	1. It is division of cytoplasm to form two daughter cells.
2. There is disorganization of nuclear envelope, appearance of already replicated chromosomes, their splitting and equitable distribution.	2. There is no such elaborate mechanism of equitable distribution of cell organelles.
3. It is first step of M-phase.	3. It is last step of M-phase.

Animal Cytokinesis. The central equatorial part of spindle gets changed into dense fibrous and vesicular structure called **midbody.** Simultaneously, microfilaments collect in the middle region of the cell below the cell membrane. They induce the cell membrane to invaginate. The furrow deepens centripetally and cleaves the cell into two daughters, each having a daughter nucleus. The method is known as **cleavage cytokinesis.**

Plant Cytokinesis. Plant cytokinesis is different from animal cytokinensis due to presence of a solid cell wall on the outside. It takes place by two methods, cleavage and cell plate.

1. **Cleavage Method.** It takes place usually in some lower plants. Cytoplasm undergoes centripetal constriction in the middle to form two daughter protoplasts, each having a single nucleus. In the furrow between the two protoplasts, pectin hemicellulose and microfibrils of cellulose are deposited to form a double wall. Wall development is centripetal like the cytoplasmic cleavage.

2. **Cell Plate Method** (Fig. 10.9). It is a common method of cytokinesis in plant cells. In his case the spindle persists for some time. It is known as **phragmoplast**.

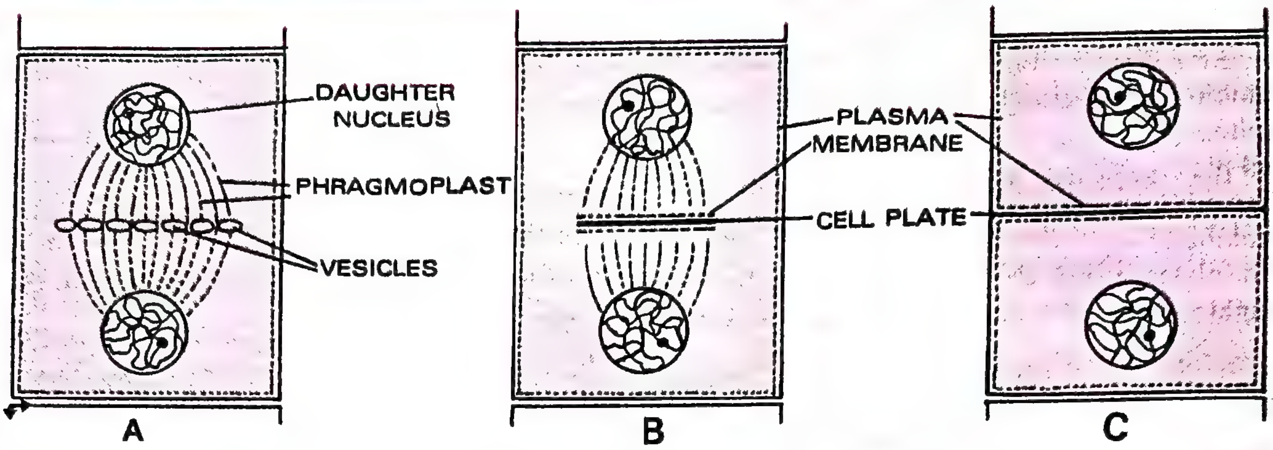


Fig. 10.9. Cytokinesis by cell plate method in plant cells.

Small vesicles produced by Golgi apparatus collect at the equator of the phragmoplast. The membrane of the vesicles fuse to form two sheets which enclose a matrix or **film.** Soon the film becomes solidified to form **cell plate** or middle lamella. It grows centrifugally and comes in contact with lateral walls of parent cell. With the formation of the cell plate the spindle or phragmoplast disappears. The daughter protoplasts deposit cellulose, hemicellulose and pectin on either side of the cell plate. They form the primary wall.

Differences between Plant Cytokinesis and Animal Cytokinesis

Plant Cytokinesis	*Animal Cytokinesis*
1. It usually occurs by cell plate method.	1. It takes place by cleavage.
2. The spindle usually persists during cytokinesis.	2. The spindle begins to degenerate soon after anaphase.
3. Central part of spindle grows in size and forms an interdigited complex called phragmoplast.	3. A mid body of dense fibrous and vesicular material is formed in the middle.
4. Vesicles derived from Golgi apparatus reach the equator of the phragmoplast and fuse to form cell plate and new cell membranes.	4. The event is absent in animal cytokinesis.
5. Cell plate grows centrifugally.	5. Cleavage progresses centripetally.
6. The new cell membrane is derived from vesicles of Golgi apparatus.	6. The new cell membrane is usually derived from endoplasmic reticulum.

Differences between Plant and Animal Mitosis

Plant Mitosis	*Animal Mitosis*
1. It occurs generally in the region of a meristem.	1. It occurs at several places.
2. Plant mitosis is generally controlled by hormone cytokinin.	2. Animal motisis is controlled by a number of mitogens like lymphokines, epidermal growth factor, platelet derived growth factor, etc.
3. The cell does not change shape prior to division.	3. The cell often becomes spherical pior to division.
4. Spindle is anastral.	4. Spindle is amphiaster (= astral) with one aster at each pole.

5. Centrioles are absent.	5. The spindle poles possess centriole pairs.
6. The equatorial region of the spindle forms phragmoplast.	6. The equatorial region of the spindle forms midbody.
7. Cytokinesis generally occurs by cell plate method.	7. Cytokinesis occurs by cleavage.
8. Cell plate grows centrifugally.	8. Cleavage proceeds centripetally.
9. Microfilaments do not have much role in cytokinesis.	9. Microfilaments bring about cleavage.
10. Cell plate or middle lamella cements the daughter cells.	10. Cleavage creates an intercellular space between the daughter cells.

Significance of Mitosis

1. **Growth**. Somatic cells are formed by mitosis. Therefore, mitosis is essential for growth and development of a multicellular organism. Human baby has about 6×10^{12} cells. All of them develop from a single celled zygote through repeated mitosis. Plants are able to grow throughout their life due to mitotic divisions in their apical and lateral meristems.

2. **Maintenance of Surface/Volume Ratio**. An overgrown somatic cell is induced to divide so that mitosis helps in maintaining a proper surface/volume ratio.

3. **Nucleocytoplasmic Ratio.** An efficient cell has a high nucleocytoplasmic ratio. Increase in size lowers the ratio. It is brought back to efficient level through division.

4. **Maintenance of Chromosome Number**. Mitosis involves replication and equitable distribution of all the chromosomes so that all the cells of a multicellular organism have the same number and type of chromosomes. This helps in proper co-ordination among different cells.

5. **Regeneration.** Mitosis keeps all the somatic cells of an organism genetically similar, resembling the fertilized egg. They, therefore, are able to regenerate part or whole of the organism.

6. **Reproduction**. Mitosis is the method of multiplication of unicellular organisms.

7. **Repair.** It is a mechanism for replacing old or worn out cells. In human body roughly 5×10^9 cells are daily lost from surface of skin, lining of alimentary canal, RBCs, WBCs, etc. The same are replaced by new cells formed through mitosis.

8. **Healing**. An injury or wound is healed by repeated mitotic divisions of the surrounding healthy cells.

9. **Opportunity for Differentiation.** Mitosis produces multicellular condition. It provides opportunity for differentiation.

10. **Cancer.** Uncontrolled mitotic division leads to cancer.

11. **Evidence of Basic Relationship**. The details of mitosis are similar in the majority of organisms, showing their basic similarity and relationship.

MEIOSIS

Meiosis (Gk. *meioum* or *meio–* to lessen) *is a double division which occurs in a diploid cell (or nucleus) and gives rise to four haploid cells (or nuclei), each having half the number of chromosomes as compared to the parent cell.* The term meiosis was coined by Farmer and Moore in 1905. The division was first of all studied by Van Benedin (1887), Strasburger (1888), Sutton (1900) and Winiwater (1900).

Interphase occurs prior to meiosis. It is similar to interphase of mitosis except that S-

phase is prolonged. DNA replication occurs during S-phase. A distinct G_2 phase is either short or absent. At this time each chromosome comes to have two chromatids. Chromosome

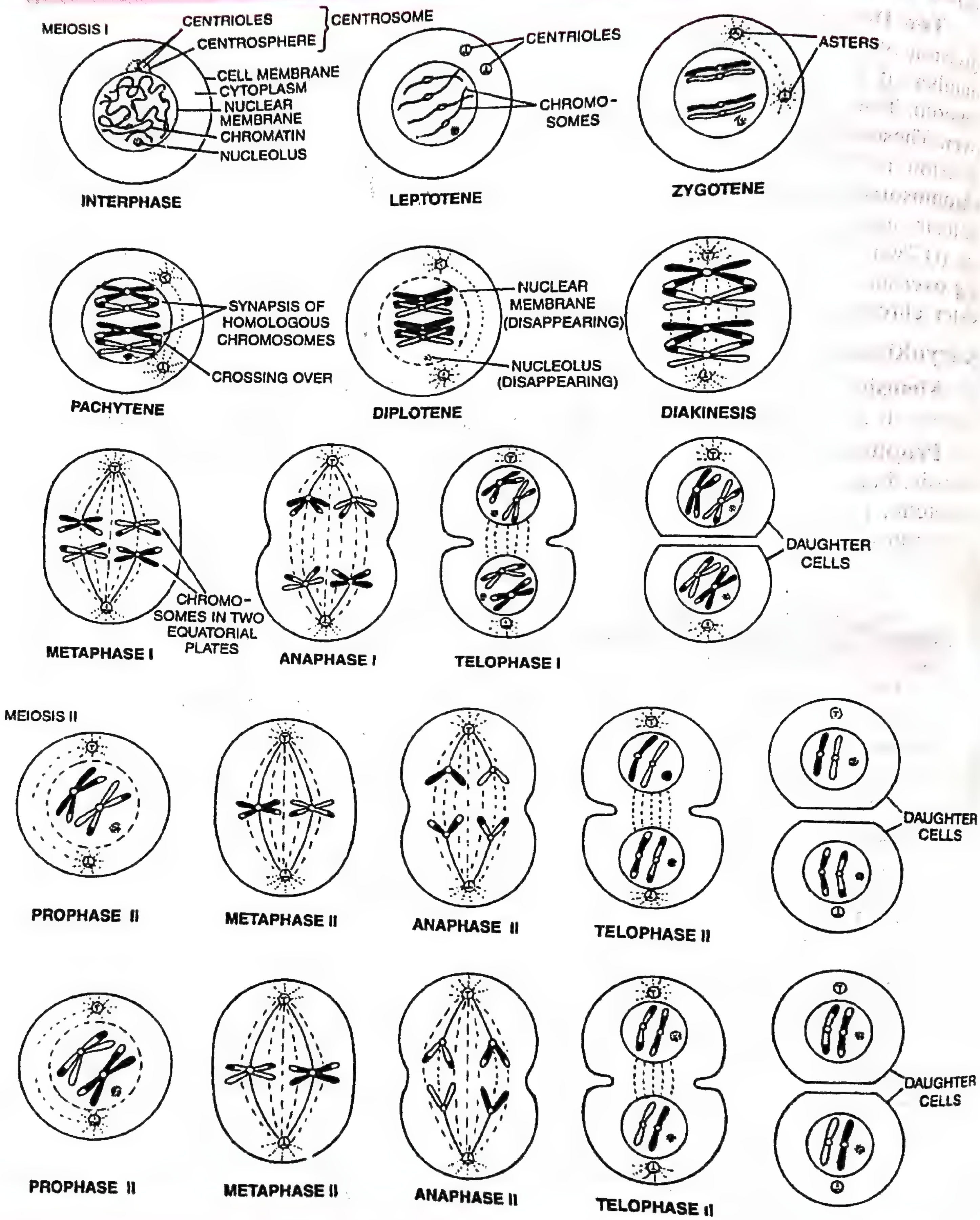


Fig. 10.10. Different stages of Meiosis in animal cell.

replication occurs once but meiosis has two M-phases each with its own Karyokinesis and Cytokinensis. As a result chromosome number is halved. The transition period between M-phase I (meiosis I) and M-phase II (meiosis II) is short and without DNA replication. It is called **interkinesis.**

Two Divisions. Meiosis consists of two divisions, meiosis I and meiosis II. The first division of meiosis is called **heterotypic** or **reduction division**. During this division the number of chromosomes is reduced to half. Segregation of chromosomes is, however, random. The two chromatids of a chromosome become genetically different due to crossing over. These chromatids are separated in the second division of meiosis. The second meiotic division is known as **homotypic** (= homoeotypic) or **equational division**, because the chromosome number remains the same as produced after the end of the first division. Like mitosis, meiosis also involves **indirect nuclear division**. The essential features of meiosis are (i) Two successive divisions but no DNA replication prior to second division. (ii) Crossing over and formation of chiasmata between homologous chromosomes. (iii) Separation of sister chromatids which have undergone change due to crossing over.

Karyokinesis

Meiosis I. The heterotypic or reduction division is the first division of meiosis. Like mitosis, it is studied under four stages— prophase, metaphase, anaphase and telophase.

Prophase I. It is more complicated and prolonged as compared to the similar stage of mitosis. For the sake of convenience, prophase I is divided into five sub-phases— leptotene, zygotene, pachytene, diplotene and diakinesis. Another sub-phase called **preleptonema** is sometimes recognised prior to leptonema. In this phase chromosomes are not distinguishable because of their thinness but sex chromosomes (if present) are often seen as heterochromatic (heteropycnotic) bodies.

1. **Lepotene** or **Leptonema** (Gk. *leptos*– slender, *tainia*– band, *nema*– thread). Nucleus enlarges. Their ends, however, remain attached to nuclear envelope through a special structure called **attachment plate**. The chromatin fibres of interphase nucleus shorten and elongated chromosomes become clear. They possess a string of swollen areas called **chromomeres**. Chromomeres are often believed to represent genes. The chromosomes are replicated but the chromatids are not distinguishable due to the presence of **nucleoprotein core** between them. In many animal cells the chromosomes show a peculiar arrangement called **bouquet stage.** Here the ends of chromosomes converge towards the side having replicated centrosomes or centriole pairs. One of the two centiole pairs begins to move to the opposite side. Both the centriole pairs or centrosomes develop astral rays from the pericentriolar satellites. Each centriole pair and its astral rays together constitute aster.

In cells undergoing meiosis, there are two sets of chromosomes, that is, the chromosome number is **diploid**. There are two similar chromosomes of each type. Such chromosomes are called **homologous chromosomes**. The two homologous chromosomes are contributed by different parents. One of them belongs to the father parent and is called **paternal chromosome**. The other chromosome of homologous pair belongs to the mother parent and is called **maternal chromosome**. The homologous chromosomes resemble each other in the position of their centromeres, position of chromomeres, shape and size.

2. **Zygotene or Zygonema** (Gk. *zygon*– yoke or tied, *tainia*– band). The two homologous chromosomes get attached to each other laterally due to development of nucleoprotein between them. It is similar to nucleoprotein core present between two chromatids of a chromosome. Pairing is such that the genes of the same character present on the two chromosomes come to lie exactly opposite. The process of attachment of the homologous

chromosomes is known as **synapsis** (Montgomery, 1901) or syndesis. Depending upon the place of origin of pairing, synapsis is **procentric** (starting from centromeres and proceeding towards ends), proterminal (starting from ends and proceeding towards centromeres) and **intermediate** (at various places in between centromeres and ends). It produces a complex known as **synaptonemal complex** (Moses, 1956). In a synaptonemal or synaptinemal complex, ribonucleoprotein core has a tripartite structure, one central and two lateral longitudinal elements which are connected by lateral elements. Each lateral element occurs in between two chromatids of a chromosome. Central element lies between the two homologous chromosomes (Fig. 10.11). On account of synapsis, chromosomes form pairs or **bivalents**. The number of bivalents is half the number of the total chromosomes.

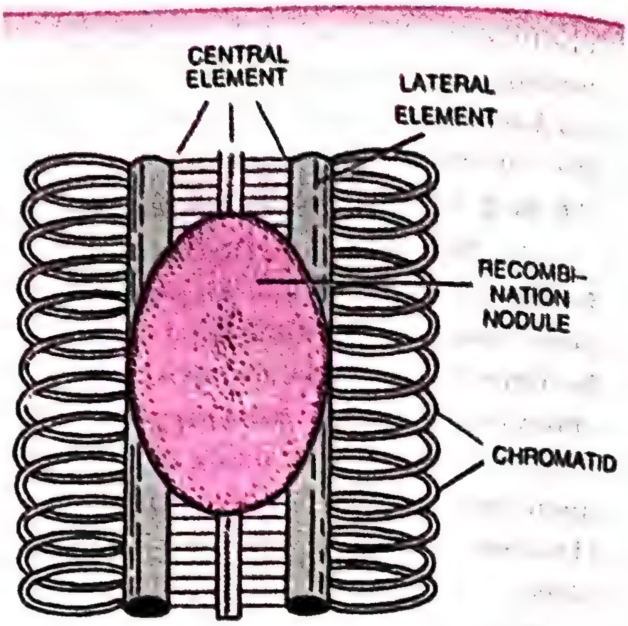


Fig. 10.11. Recombination nodule and synaptonemal complex.

3. **Pachytene or Pachynema** (Gk. *pachys*– thick, *tainia*– band). Soon after completion of synapsis, the cell enters pachytene stage. In this stage it can remain for days. Chromosomes are paired and occur in synaptonemal (= synaptinemal) complexes. The paired chromosomes or bivalents shorten. Each bivalent or chromosome pair is made up of actually four chromatids, two of each chromosome. The two chromatids belonging to the same chromosome are called **sister chromatids**. Chromatids belonging to the two different chromosomes of a homologous pair are termed as **nonsister chromatids**.

Dense areas appear here and there over the bivalents (Fig. 10.12). They are called **recombination nodules** (Zickler *et al*, 1977). Nodules contain multienzyme complexe called **recombinase**. Recombinase is made of endonuclease, exonuclease, unwindase, R-protein, etc. In the presence of enzyme **endonuclease** (Stern and Hota, 1969, 1978) breaks develop in the individual chromatids. The process is called **nicking**. In most of the cases, the nicks get healed but in one out of 1000, gaps develop in the region of nicks by the activity of another enzyme called **exonuclease**.

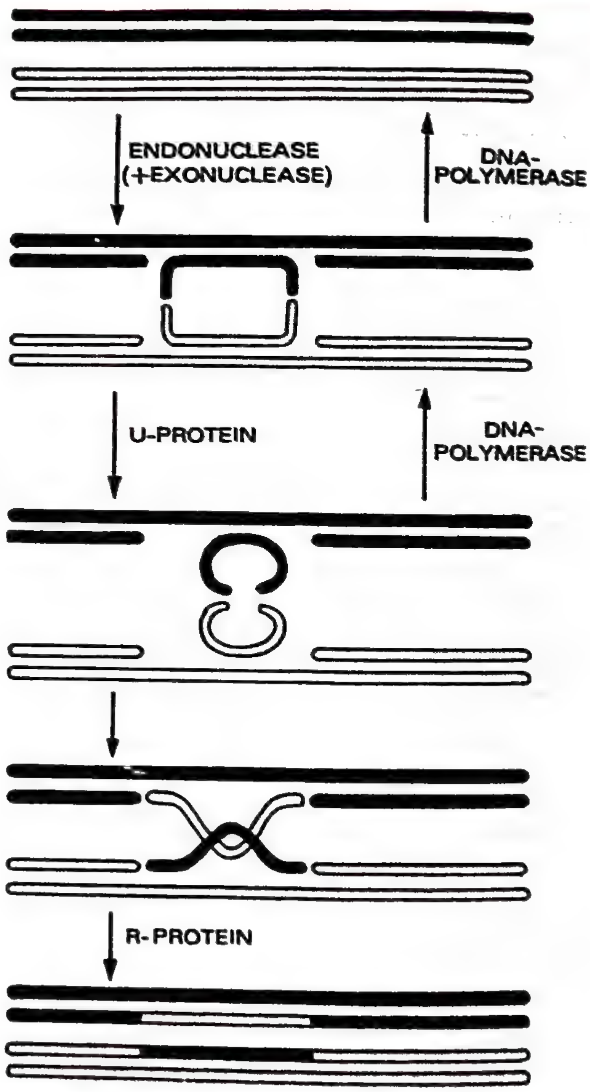


Fig. 10.12. Steps in pachytene of prophase I

Separation of chromatid segments occurs in between two gaps by **U-protein** or **enzyme unwindase**. The separated segments of nonsister

chromatid segments may exchange position if they happen to show the same degree of nicking. The phenomenon is called crossing over (Fig. 10.13). Crossing over is *a process of exchange of genetic material or chromatid segments between two homologous chromosomes*. It is an enzyme mediated process. The separated chromatid segments soon get re-united with the help of an enzyme known as **R-protein.** The process is called **re-annealing**.

4. **Diplotene or Diplonema** (Gk. *diplos–* double, *tainia–* band). The nucleoprotein fusion complex of the synapsed chromosomes dissolves partially. Therefore, the homologous chromosomes separate except in the region of crossing over. The chromatids also become distinguishable (tetrad stage). The points of attachment between the homologous chromosomes after the partial dissolution of nucleoprotein complex are called **chiasmata** (Gk. *chiasma–* cross, Johanssen, 1909). Chiasmata may be terminal or interstitial. Depending upon their position the homologous chromosomes appear cross-like, ring-like or chain like. However, they are not permanent structures. They shift side-ways or even disappear at places.

Diplotene is extended and metabolically active in animal cells, especially oocytes because bulk of gametic growth occurs during this phase. In some oocytes, diplotene stage can last for months and years. In such cases, chromosomes decondense and get engaged in RNA synthesis. **Lampbrush chromosomes** are actually decondensed diplotene chromosomes.

5. **Diakinesis** (Gk. *dia–* through, *kinesis–* movement). Chiasmata shift towards the ends of the chromosomes. The phenomenon is called **terminalisation**. The bivalent of satellite chromosomes remains united with the nucleolus for some time. The nucleolus ultimately degenerates. Simultaneously, nuclear envelope disintegrates.

Metaphase I. A colourless bipolar spindle apparatus appears in the region of degenerated nucleus. It consists of fine fibres. The fibres converge towards the two ends called poles. In animal cells the poles are formed by asters. The spindle fibres are formed of microtubules. The spindle apparatus has the maximum diameter in the middle region which is called equator.

The bivalents arrange themselves on the equator of the bipolar spindle. The limbs of the chromosomes are usually short and lie horizontally on the equator. The centromeres slightly project towards the periphery. Since, there are two centromeres in each bivalent, the centromeres of all the bivalents produce a **double metaphasic plate**.

The distribution of bivalents is at random so that the individual paternal and maternal chromosomes can face either of two poles of the spindle. Each chromosomes gets attached to the spindle pole of its side by means of a **chromosome fibre** or **tractile fibril** which arises in the region of the centromere. (This is in contrast to the development of two tractile fibrils from the same centromere

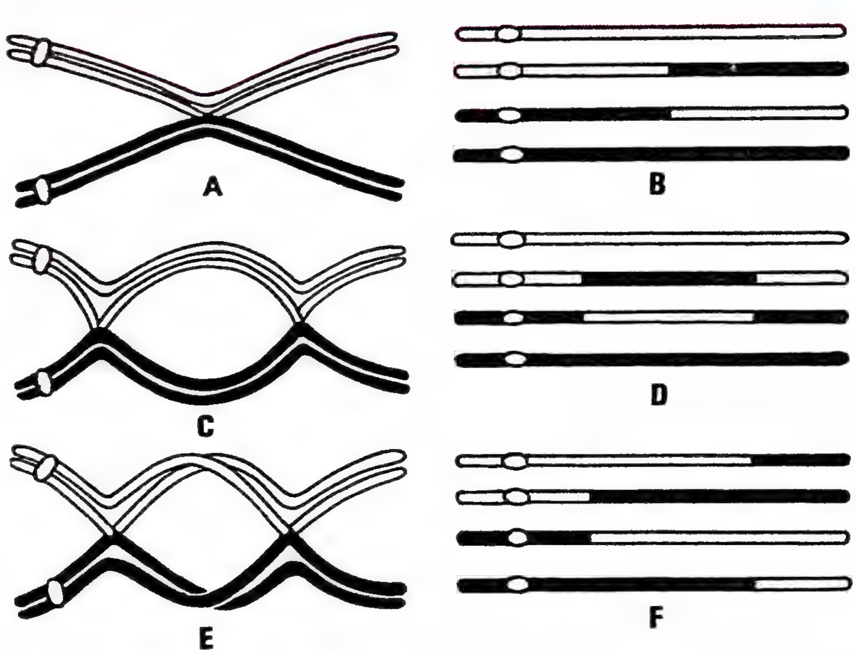


Fig. 10.13. Crossing over. A-B at one point. C-D at two points. E-F, crossing over amongst four nonsister chromatids

in mitosis). The fibres of the homologous chromosomes are always in the opposite directions.

Anaphase I. The homologous chromosomes break their connections and separate out. The process of separation is named as **disjunction** (*dis*– separate, *junction*– union). The separated chromosomes or **univalents** are also called **dyads** (Gk. *dyas*– two) because each of them consists of two chromatids which lie at an angle to each other. The double stranded chromosomes of anaphase I are in sharp contrast to their single-stranded nature in anaphase of mitosis.

The chromosomes move towards the spindle poles along the path of their tractile fibrils. At the end of anaphase I, two groups of chromosomes are produced, with each group having half the number of chromosomes present in the parent nucleus.

Telophase I. The polar groups of chromosomes arrange themselves into haploid or dyad nuclei. The chromosomes elongate. A nucleolus is formed by the satellite chromosome. It is followed by the appearance of nucleoplasm and nuclear envelope. The elongated chromosomes usually remain straight and do not enter the interphase. In some cases telophase is completely omitted when the anaphase chromosomes directly enter the metaphase of homotypic division (*e.g., Trillium*). Similarly, cytokinesis may or may not follow division I of meiosis.

Significance of Meiosis I

1. It separates the homologous chromosomes and reduces the chromosome number to one half. This is essential for sexual reproduction.
2. Crossing over occurs during this division. It introduces new combinations of genes or recombinations. Recombinations result in variations.
3. There is random distribution of paternal and maternal chromosomes into daughter cells. It is a sort of independent assortment and produces variations.
4. Due to disturbance in disjunction, chromosomal and genomatic mutations take place.
5. Meiosis I induces the cells to form spores or gametes.

Interkinesis or Intrameiotic Interphase

It is metabolic stage between telophase of meiosis I and prophase of meiosis II. Chromosomes are elongated but chromatin reticulum is not formed. Protein and RNA synthesis may occur. Centrosomes or centriole pairs undergo replication in animal cells. However, there is no DNA synthesis. It is important for bringing true haploidy (haploidy of DNA) in daughter cells.

Meiosis II. It is shorter than the typical mitotic division because of the shortening of prophase of this division. The division maintains the number of chromosomes produced at the end of reduction division. It is hence called **homotypic** or **equational division**. Though it is similar to mitosis, **meiosis II is not mitosis** because (i) It always occurs in haploid cells. (ii) It is not preceded by DNA replication. (iii) The two chromatids of a chromosome are often dissimilar. (iv) The daughter cells formed after meiosis II are neither similar to each other nor similar to the parent cell.

The main function of homotypic division or meiosis II is to separate the chromatids of univalent chromosomes which differ from each other in their linkage groups due to crossing over. Meiosis II is divisible into prophase, metaphase, anaphase and telophase.

Prophase II. This stage of nuclear division is very brief. It takes place simultaneously in the two nuclei. In animal cells, the centriole pairs develop asters and move to the regions

of future spindle poles. The dyad chromosomes shorten a little. Nucleolus and nuclear envelope degenerate. The chromatids of individual chromosomes are usually divergent and are hence much looser than the ones in somatic division. In case where telophase I is omitted, the prophase II is completely absent.

Metaphase II. Achromatic bipolar fibrous spindles are formed in the areas of dividing nuclei. They are amphiastral in case of animal cells and anastral in case of plant cells. The spindles are arranged in isobilateral or tetrahedral fashion. The chromosomes reach the respective spindle and arrange themselves in such a fashion that their centromeres come to lie at the equator. Each chromosome gets connected with both the spindle poles by means of chromosome fibres or tractile fibrils that develop from both the surfaces of its centromere. The centromeres give out chromosome fibres or tractile fibrils from both their surfaces towards the spindle poles.

Anaphase II. The centromere of each chromosome divides into two so that there is one centromere for each chromatid. The two chromatids of a chromosome separate completely and are called **daughter** or **new chromosomes**. The daughter chromosomes move towards the spindle poles along the path of their fibres or tractile fibrils. At the end of anaphase II, four groups of chromosomes are produced, each group having haploid number.

Telophase II. The four groups of chromosomes arrange themselves into haploid nuclei. For this, chromosomes elongate very much to form chromatin. A nucleolus is also produced. This is followed by the formation of nucleoplasm and a nuclear envelope. The spindle fibres usually degenerate during telophase II.

Cytokinesis

Cytokinesis can be of two types, **successive** and **simultaneous**. In successive type, cytokinesis occurs after every nuclear division. It produces two cells after the heterotypic division. Both the cells undergo homotypic divisions and then give rise to four cells. The four cells formed by successive cytokinesis can be arranged either in a linear or isobilateral tertrad.

In the simultaneous type, cytokinesis takes place only at the end of both the divisions. The nuclei are generally arranged in the form of a tetrahedron. Cytoplasm cleaves or constricts in between the nuclei. Four furrows are formed. They deepen and meet in the centre of the parent cell. In plants, wall material is deposited in the furrows. It gives rise to four haploid cells. These haploid cells are arranged tetrahedrally and are collectively called tetrahedral tetrad.

Significance of Meiosis

1. **Formation of Gametes**. Meiosis forms gametes that are essential for sexual reproduction.

2. **Genetic Information**. It switches on the genetic information for the development of gametes or gametophytes and switches off the sporophytic information.

3. **Maintenance of Chromosome Number**. Meiosis maintains the fixed number of chromosomes in sexually reproducing organisms by halving the same. It is essential since the chromosome number becomes double after fertilization.

4. **Assortment of Chromosomes.** In meiosis paternal and maternal chromosomes assort independently. It causes reshuffling of chromosomes and the traits controlled by them. The variations help the breeders in improving the races of useful plants and animals.

5. **Crossing over.** It introduces new combination of traits or variations.

6. **Mutations.** Chromosomal and genomatic mutations can take place by irregularities of meiotic divisions. Some of these mutations are useful to the organism and are perpetuated by natural selection.

7. **Evidence of Basic Relationship of Organisms.** Details of meiosis are essentially similar in the majority of organisms showing their basic similarity and relationship.

Need for Meiosis

Meiosis is essential for all sexually reproducing organisms. It occurs in reproductive cells so that the gametes formed are haploid or have half the number of chromosomes of those cells, which are directly derived from zygote. Two types of gametes fuse during zygote formation. As a result, zygote comes to have double the number of chromosomes contained in gametes. Meiosis by halving the number of chromosomes maintains a fixed number of chromosomes of a species. In the absence of meiosis, the number of chromosomes will double with every generation resulting in excessive enlargement of nucleus, genetic degeneration and death of living beings.

Types of Meiosis

The cells in which meiosis takes place are called **meiocytes**. In animals, meiocytes are of two types, spermatocytes and oocytes. In higher plants, meiocytes are differentiated into microsporocytes and macrosporocytes. Depending upon the stage when meiosis occurs, the latter is of three types— gametic, zygotic and sporic.

1. **Gametic Meiosis.** Meiosis in most of animals takes place during the formulation of gametes (**gametogenesis**). It is termed as **gametic meiosis**. When two gametes fuse in fertilization, a **diploid** zygote is formed.Gametic meiosis results in **diplontic life cycle.**

2. **Zygotic Meiosis.** In some lower plants meiosis takes place in the zygote and the resulting organisms are haploid. It is called **zygotic meiosis**. Organisms having zygotic meiosis have **haplontic life cycle**.

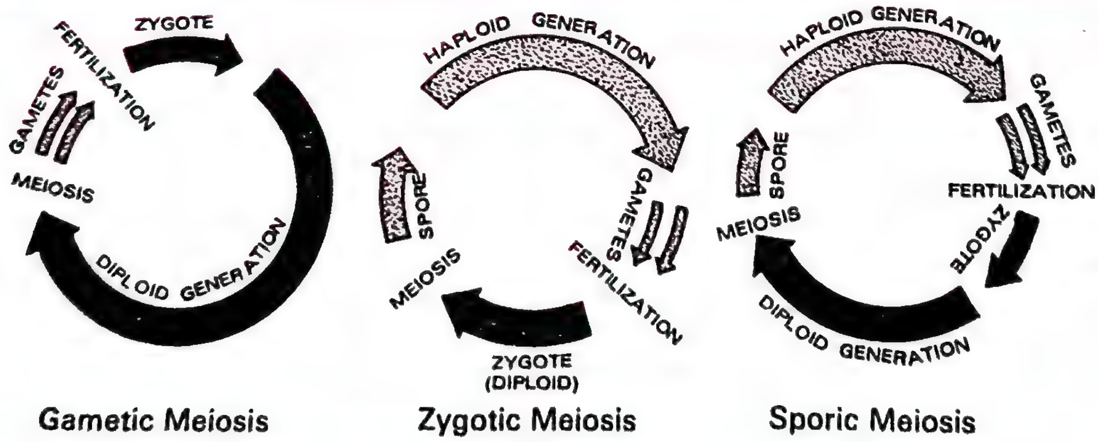


Fig. 10.14. Three types of Meiosis.

3. **Sporic Meiosis.** In plants meiosis generally occurs at the time of **sporogenesis** (formation of spores or microspores and megaspores). It is called **sporic meiosis** or **intermediate meiosis**. Spores produce a new gametophytic phase in the life cycle. Gametes are formed by gametophytes. Because of the presence of two distinct multicellular phases, diploid and haploid, life cycle of plants is diplohaplontic.

Diploid cells have two genomes while haploid cells have a single genome. *A genome is a complete complement or set of chromosomes where each kind is represented by a single chromosome.*

Differences between Mitosis and Meiosis

Mitosis	*Meiosis*
1. Mitosis takes place in the somatic cells.	1. It occurs either in the reproductive cells or at the time of germination of zygote or zygospore.
2. The cells undergoing mitosis may be haploid or diploid.	2. The cells undergoing meiosis are always diploid.
3. It is a single division which produces two cells.	3. Meiosis is a double division. It gives rise to four cells.
4. Interphase occurs prior to each division.	4. Interphase precedes only meiosis I. It does not occur prior to meiosis II.
5. Mitosis is comparatively simple.	5. Meiosis is quite complicated.
6. It takes less time to complete.	6. It takes longer time to complete.
7. A cell can undergo repeated mitosis.	7. Meiosis occurs only once.
8. Subsequent mitotic divisions are similar to the earlier ones.	8. The two divisions of meiosis are not similar. The first one is heterotypic or reductional while the second one is homotypic or equational like mitosis.
9. Each chromosome replicates in the interphase before every division.	9. The chromosomes replicate only once, prior to meiosis.
10. The number of chromosomes remains the same after mitosis.	10. The number of chromosomes is reduced to one half after meiosis.
11. The daughter nuclei or cells formed after mitosis are exactly similar to the parent one.	11. The daughter nuclei or cells formed after meiosis are neither similar to the parent one nor to one another.
12. Meiosis helps in multiplication of cells.	12. Multiplication of cells is not involved.
13. Mitosis takes part in healing and repair.	13. Meiosis takes part in the formation of meiospores or gametes and maintenance of chromosome number of the race.
14. No variations are introduced.	14. It introduces variations.
Prophase	
15. Chromomeres are not conspicuous.	15. Chromomeres are quite conspicuous.
16. Prophase is of shorter duration.	16. Prophase I is of longer duration while prophase II is very brief.
17. Prophase is simpler and is hardly distinguishable into substages.	17. Prophase I is complicated and is divisible into five substages. Prophase II is, however, very simple.
18. Each chromosome has two distinct chromatids.	18. Chromosomes of prophase I do not show distinct chromatids.
19. No bouquet stage is recorded.	19. Chromosomes of animals and some plants show convergence towards one side during early prophase I. It is known as bouquet stage.
20. Pairing of chromosomes does not occur in mitosis.	20. Pairing or synapsis of homologous chromosomes takes place during zygotene of prophase I and continues upto metaphase I.
21. A synaptinemal complex is absent.	21. Synapsed homologous chromosome develop a synaptinemal complex.
22. Crossing over is absent.	22. Crossing over or exchange of similar segments between nonsister chromatids of homologous chromosomes usually takes place during pachytene stage.

23. Chiasmata are absent.	23. Chiasmata or visible connections between homologous chromosomes of bivalents are observed during diplotene, diakinesis (pro-phase I) and metaphase I.
Metaphase	
24. Centromeres produce a single metaphasic plate.	24. A double metaphasic plate is formed by centromeres in metaphase I but only one in metaphase II.
25. Chromosomes are independent and do not show connections.	25. Homologous chromosomes are inter-connected. Hence the chromosomes occur in pairs or bivalents in metaphase I. They are, however, free in metaphase II.
26. Only the centromeres lie at the equator. The limbs of chromosomes are oriented in various directions.	26. Limbs of the chromosomes mostly lie at the equator while the centromeres project towards the poles in metaphase I.
27. A centromere is connected with both the spindle poles.	27. A centromere is connected to one spindle pole in metaphase I but both in metaphase II.
28. Two chromatids of a chromosome are genetically similar.	28. The two chromatids of a chromosome are often genetically different due to crossing over.
Anaphase	
29. A centromere splits length-wise to form two centromeres in the beginning of anaphase.	29. Centromeres do not divide during anaphase I but do so in anaphase II.
30. Anaphasic chromosomes are single stranded.	30. Chromosomes are double stranded in anaphase I but single stranded in anaphase II.
31. Similar chromosomes move towards the opposite poles in anaphase.	31. Dissimilar chromosomes move towards the opposite poles both in anaphase I and anaphase II.
Telophase	
32. Telophase is longer and produces interphase nuclei.	32. Telophase I is shorter and nuclei never enter the interphase.
Cytokinesis	
33. Cytokinesis follows every mitosis. It produces two new cells.	33. Cytokinesis often does not occur after the first or reductional division. It is then simultaneous after second division to result in four new cells.

Colchicine

It is an alkaloid widely used in plant breeding for doubling the chromosome number. Colchicine is extracted from the corms of Autumn Crocus (*Colchicum autumnale*). The alkaloid does not allow the formation of spindle because it prevents assembly of microtubules. It is, therefore, called "mitotic poison". The chemical does not inhibit chromosome replication. As a result the colchicine treated meristematic cells show doubling of chromosomes. This property of increasing the number of chromosome sets or genomes is called **polyploidy**. Polyploidy provides (i) New varieties and species (ii) Vigorous offspring. Colchicine induced polyploidy has been used in raising several varieties of horticultural and agricultural plants, *e.g.*, Potato.

ADDITIONAL INFORMATION

- **Centrioles.** They are not essential for cell division as spindles are formed without them in plants. Amphiaster or astral division is a mechanism to distribute centriole pairs to the daughter cells.
- **Anaphase.** It has two stages. In anaphase **A**, the chromosome fibres shorten causing the poleward movement of chromosomes. In anaphase **B**, the spindle elongates.
- **Chromosome Shortening.** A metaphasic chromosome has only 4% of the length of the original chromatin fibre. Reduction in size is due to condensation of scaffold proteins, coming together of chromatin loops and their coiling.
- **Intranuclear Spindle Formation.** In fungi, many algae, *Amoeba*, etc. the nuclear envelope does not degenerate. However, polar pores may appear. An internal spindle is formed which is called intranuclear spindle. It helps in equitable distribution of chromosomes.
- The term **karyokinesis** was coined by Schneider (1887) while **cytokinesis** was coined by Whiteman (1887).
- **Dinomitosis.** Dinoflagellates possess condensed chromosomes even in interphase. Their nucleus is called **mesokaryon.** Nuclear envelope and nucleolus persist during mitosis. An intranuclear spindle is also not formed. Instead, cytoplasmic channels develop in the nucleus to help in the passage of replicated chromosomes to the two ends along the nuclear envelope.
- **Mitotic Poisons.** Colchicine, chalones, cyanides, azides.
- **Phragmoplast.** Persistent part of spindle apparatus with an interdigitated array of microtubules at the equator.
- **Syndetic Knot.** In certain plants, all the leptotene chromsomes come in contact at one point to diverge again. The point of contact is called syndetic knot.
- **Antephase.** Stage in cell cycle when cell stores energy as ATP for completion of cell division (Bullough,1952). It is G_1.
- **Endomitosis** (Endoduplication). It is replication of chromosomes without corresponding division of nucleus.
- **Free Nuclear Division.** It is division of nucleus without being followed by cytokinesis. It gives rise to **multinucleate** condition.
- **Polytene Chromosomes** (Salivary chromosomes; Balbiani, 1881). They are giant chromosomes formed by repeated replication of somatically synapsed homologous chromosomes. A polytene chromosome may have upto 1000 strands.
- **Diplotene Chromosomes** (Ruckert, 1892). Giant chromosomes called **lampbrush chromosomes** where two homologous chromosomes with several chiasmata show lateral loops in chromomeric regions for rapid synthesis of yolk. The chromosomes occur in oocytes and disappear after completion of diplotene stage.
- **Material used to study mitosis and meiosis in classroom :— (i) onion/broad bean root tips for mitosis. (ii) Young anthers from unopened floral bud of onion or testes of Grass hopper for meiosis.**

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. What is the average cell cycle span for a mammalian cell ?

   ✓ 24 hrs.

2. Describe events taking place during interphase.

   ✓ Interphase is the phase in the cell cycle that prepares a cell and its nucleus for division. It has three stages — G_1, S and G_2.

   G_1 Phase is the longest stage of interphase, also called first growth phase or post-mitotic gap phase. Both the cell and its nucleus grow in size. There is synthesis of RNA, proteins, nucleotides, amino acids for histones and energy rich compounds. There is a check point, called **G_1 cyclin** or **CG_1**, where decision about entry in G_0 or S-stage is made. Once the check point is crossed, cell cycle will go on uninterrupted till it is completed.

   S-Phase. Chromosomes alongwith their DNAs replicate. DNA content doubles. After replication, the daughter chromosomes remain attached in the region of centromere. Centrosome, if present, begins to divide. S-phase of interphase is also called invisible phase of M-stage.

G_2-Phase. There is increased synthesis of RNA and proteins. Cell organelles or their precursors multiply. Cell grows in size. G_2-phase is also called second growth phase or pre-mitotic gap phase. Mitotic cyclin (C_M) prepares the cell to enter the M-phase.
In cells where G_1 cyclin is not available, the S-phase is seldom accomplished. The cell enters G_0-phase in which stage it may remain in undifferentiated stage as reserve cell or become differentiated to perform a particular function.

3. What is G_0 (quiescent phase) of cell cycle ?
✓ It is the stage of inactivation of cell cycle due to non availability of mitogens and energy rich compounds. Cells in this quiescent stage remain metabolically active and act as reserve cells or undergo growth and differentiation for specific function. The cells in quiescent centre of root tip are in G_0 stage.

4. Why is mitosis called equational division ?
✓ Mitosis is called equational division because it involves equal distribution of chromosomes into daughter cells.

5. Name the stage of cell cycle at which one of the following events occurs. (i) Chromosomes are moved to spindle equator. (ii) Centromere splits and chromatids separate. (iii) Pairing between homologous chromosomes takes place. (iv) Crossing over between homologous chromosomes takes place.
✓ (i) Metaphase (ii) Anaphase (iii) Zygotene of prophase I of meiosis I (iv) Pachytene of prophase I of meiosis I.

6. Describe the following : (a) Synapsis (b) Bivalent (c) Chiasmata. Draw a diagram to illustrate your answer.
✓ (a) **Synapsis.** It is pairing of homologous chromosomes that occurs during zygotene of prophase I. During synapsis, the similar chromomeres of the two chromosomes come to be exactly opposite.
(b) **Bivalent.** It is a synapsed pair of homologous chromosomes.
(c) **Chiasmata.** They are points of attachment between homologous chromosomes during their separation in diplotene to metaphase I stage of meiosis. Chiasmata are initially formed in the regions of crossing over between nonsister chromatids but later on tend to shift sideways. Fig. 10.10 zygotene (for synapsis, also for bivalent), Diplotene (for chiasmata).

7. Find examples where the four daughter cells from meiosis are equal in size and where they are found unequal in size.
✓ (i) Equal daughter cells are formed from meiosis in sporogenesis (spore formation in bryophytes and vascular plants where all four spores in a spore tetrad are equal in size), Spermatogenesis (sperm formation in testes).
(ii) Unequal daughter cells are formed from meiosis in oogenesis where egg cell is larger and polar bodies are smaller in size.

8. Discuss with your teacher about
(i) Haploid insects and lower plants where cell division occurs. (ii) Some haploid cells in higher plants where cell division does not occur. (iii) Some diploid cells in animals where cell division doesnot occur.
✓ (i) Drones of honey bee, gametophyte of Algae, Bryophytes, Pteridophytes and other seeded plants. (ii) Synergids & Antipodals in embryo sac of ovule. (iii) Heart cells, muscle cells & nerve cells.

9. Can there be mitosis without DNA replication in 'S' phase ?
✓ No, except cytokinesis in multinucleate structure like nuclear endosperm.

10. Can there be DNA replication without cell division ?
✓ Yes, *e.g.,* free nuclear division, polyteny.

11. Analyse the events during every stage of cell cycle and notice how the following two parameters change. (i) Number of chromosomes (N) per cell. (ii) Amount of DNA content. (C) per cell. (*NCERT*)
✓ The number of chromosomes and amount of DNA are changed in anaphase and S phase respectively. (i) **In S phase,** number of chromosomes remain same but each chromosome replicates so that it comes to have two chromatids. Due to this the DNA contents doubles from 1C to 2C or 2C to 4C depending upon haploid/diploid nature of cell.
(ii) **In Anaphase.** In mitotic anaphase, number of chromosome remains the same. It is only sister chromatids which move towards their respective poles. DNA contents remain unchanged. In Anaphase-I of meiosis, number of chromosomes are reduced to half, *i.e.,* from 2N to 1N. DNA contents decrease to one half in Anaphase-II of Meiosis-II from 2C to 1C.

12. How does cytokinesis in plant cells differ from that in animal cells ?
✓ Refer to the text.

13. Distinguish anaphase of mitosis from anaphase I of meiosis.
    ✓ Refer to the text.
14. List the main differences between mitosis and meiosis.
    ✓ Refer to the text.
15. What is the significance of meiosis.
    ✓ Refer to the text.
16. Distinguish cytokinesis from karyokinesis.
    ✓ Refer to the text.

TEST QUESTIONS

One Mark Questions (With answers)

1. Who stated first of all that new cells are formed from division of pre-existing cells ?
   ✓ Rudolph Virchow(1855).
2. At what stage a grown up cell divides ?
   ✓ A cell divides when it has grown to a certain maximum size which disturbs the **karyocytoplasmic** or **kern-plasma ratio.**
3. Define cell division ?
   ✓ The process of formation of new or daughter cells from a pre-existing cell is known as **cell division.**
4. Which type of mitosis is known as direct cell division ?
   ✓ **Amitosis** is called **direct cell division.**
5. What is spireme stage ?
   ✓ It is the name of early prophase when elongated chromosomes occur in overlapped condition like a ball of wool without their ends being visible.
6. Which type of cell division helps in regeneration ?
   ✓ Mitosis, because it keeps all the somatic cells of an organism genetically similar, so that they are able to regenerate part or whole of the organism.
7. Name the two types of cytokinesis ?
   ✓ Successive and simultaneous.

Two Mark Questions

1. What are the causes of anaphasic movement ?
2. Explain the process of nicking and re-annealing ?
3. Write about sporic meiosis ?
4. Write a brief note on colchicine.
5. Comment upon : cell division is a continuous process.
6. Distinguish between metaphase of mitosis and metaphase I of meiosis.
7. What are chiasmata ? State their significance.
8. Why is meiosis essential in sexually reproducing organisms ?
9. What are different ways in which the pairing occurs during zygotene ?

Three Mark Questions

1. (a) What is the sequence of different phases in cell cycle ?
   (b) When does the synthesis of DNA take place during cell division ?
   (c) Describe briefly the various stages of cell cycle during the interphase preceding mitosis.
2. What is genome ? (a) How many genomes are there in a haploid cell ? (b) How many genomes are there in a haploid and a diploid cell ? (c) A cell has 24 chromosomes before cell division. How many chromosomes will be there in (i) one of the daughter cells resulting from mitotic division and (ii) one resulting from meiotic division ?
3. What marks the transition between (i) Zygotene and pachytene (ii) Pachytene and early diplotene (iii) Mitotic metaphase and anaphase?
4. (a) Give importance of mitosis ; (b) Outline the importance of meiosis ; (c) Differentiate between plant cytokinesis and animal cytokinesis.
5. With the help of diagrams only depict the events that occur during prophase I of meiotic division.
6. Describe the changes occurring in the nucleus during prophase of mitosis.
7. Anaphase I of meiosis differs from anaphase of mitosis in one essential way. Describe the difference and explain how it affects the daughter cells.

8. Why does a multicellular organism require two types of cell division ? Which of the two produces the greater number of cells?

Five Mark Questions

1. What is mitosis ? Give a short account of its various stages.
2. With help of illustration, explain the various stages of meiosis I. What is the biological significance of first meiotic division?
3. Plant X has 2n = 8 chromosomes. Sketch the various stages of meiosis in this plant.
4. What are homologous chromososmes ? What happens to homologues during meiosis ?
5. Draw diagrams to show the sequence of changes occurring in a cell during meiosis II.

MULTIPLE CHOICE QUESTIONS

(1) Synapsis occurs between (a) Spindle fibres and centromeres (b) mRNA and ribosomes (c) A male and female gamete (d) Two homologous chromosomes. *(CBSE 2009)*

(2) Which stage is marked by terminalisation of chiasmata (a) zygotene (b) pachytene (c) diplotene (d) diakinesis. *(HP PMT 2010)*

(3) During mitosis, E.R. and nucleolus begin to disappear at (a) early metaphase (b) late metaphase (c) early prophase (d) late prophase. *(CBSE 2010)*

(4) Chromosomes become visible during (a) Leptotene (b) Zygotene (c) Pachytene (d) Diplotene. *(AMU 2012)*

(5) Indentify the stage when homologous chromosomes separate but sister chromatids remain associated (a) Metaphase I (b) Anaphase I (c) Metaphase II (d) Anaphase II. *(CBSE Mains 2012)*

(6) In mitosis, chromosome duplication occurs during (a) interphase (b) prophase (c) metaphase (d) anaphase. *(JKCET 2013)*

(7) Complex formed by a pair of synapsed homologous chromosomes is known as (a) kinetochore (b) axoneme (c) equatorial plate (d) bivalent. *(NEET 2013)*

(8) During which phase (s) of cell cycle amount of DNA in a cell remains at 4C level if the initial amount is denoted at 2C (a) G_1 and S (b) only G_2 (c) G_2 and M (d) G_0 and G_1. *(CBSE 2014)*

(9) In S-phase of cell cycle (a) amount of DNA remains same in each cell (b) chromosome number is increased (c) amount of DNA is reduced to half in each cell (d) amount of DNA doubles in each cell. *(CBSE 2014)*

(10) Some cells in the adult animal do not divide. They exit G_1 phase and enter an inactive stage which is called as (a) G_2 phase (b) G_0 phase (c) S-phase (d) M-phase. *(COMED-K 2015)*

(11) During meiosis I, the number of chromosomes is (a) doubled (b) tripled (c) quadrupled (d) halved. *(JKCET 2015)*

(12) When the cell has stalled DNA replication, which check point should be predominantly activated? (a) G_1/S (b) G_2/M and M (c) G_2/M (d) M. *(NEET 2016)*

(13) Anaphase Promoting Complex (APC) is a protein degrading machinery for proper mitosis of animal cells. If APC is defective in human cell, which of the following is expected to occur ? (a) Chromosomes will not condense (b) Chromosomes will be fragmented (c) Chromosomes will not segregate (d) Recombination of chromosome arms will occur. *(NEET 2017)*

Assertion and Reason Type Questions

1. **Assertion :** Meiosis II is similar to mitosis.
Reason : Meiosis I cannot occur in haploid cells.
(A) (B) (C) (D) *(AIIMS 2013)*

ANSWERS

MULTIPLE CHOICE QUESTIONS

(1) —d (2) —d (3) —d (4) —a (5) —b (6) —a (7) —d (8) —c (9) —d (10) —b
(11) —d (12) —c (13) —c

Assertion and Reason Type Questions

(1) —B

11 TRANSPORT IN PLANTS

Plants lack both interstitial fluid as well as a regular circulation system. Even then they have to move (transport) various types of substances (gases, minerals, water, hormones, photosynthates and organic solutes) not only to short distance (from one cell to another or from one tissue to another) but also to very **long distances** such as water from roots to tops of plants or photosynthates from leaves to tips of roots. Substances move over **short distances** through diffusion and active transport supplemented by cytoplasmic streaming. Long distance transport occurs through vascular systems, xylem and phloem. This transport of substances over longer distances through the vascular tissue, *i.e.,* xylem and phloem, is called **translocation**. It occurs through **mass flow**. The direction of translocation is essentially **unidirectional** in case of water (from root to stem, leaves, flowers and fruits). It is **multidirectional** in case of minerals and organic solutes. Organic compounds are synthesised in leaves. They are exported to all other parts including every living cell, growing points, fruits and storage organs. Storage organs re-export the organic nutrients when new growth is to take place. Certain parts re-export the products of their own biosynthetic activities. Mineral nutrients are primarily picked up by roots. They are passed out upwardly to leaves, stem and growing regions. Leaves re-export many of these minerals in organic form. Senescent organs and leaves pass out most of their nutrients, especially the mineral ones, before falling down from the plant. Plant hormones and other chemical stimuli are transported in very small amounts. Some of them are transported in polarised or unidirectional manner while others diffuse to all parts. Therefore, a complex traffic of materials is going on in flowering plants, some moving to different directions, some passing out in polarised manner, with most organs receiving some substances and giving out some others.

Means of Transport

Passage of materials into and out of the cells is carried out by a number of methods—

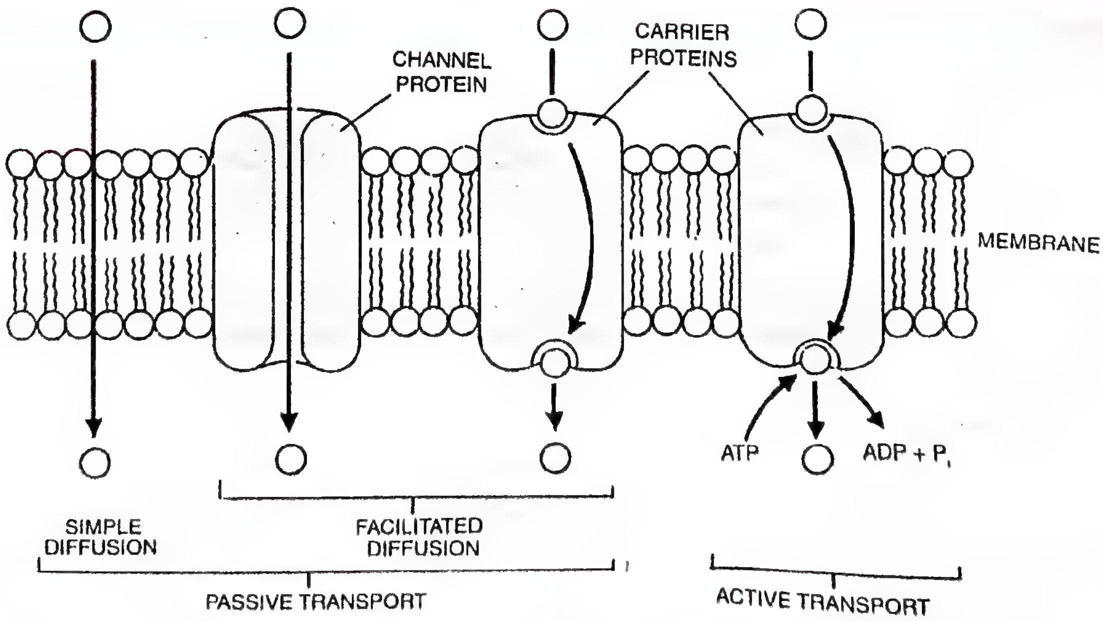


Fig. 11.1. Three ways of exchange of ions and solutes across membranes.

diffusion, facilitated diffusion, osmosis, ion channels and **active transport.**

(a) **Diffusion.** Movement by **diffusion** is passive and slow. It occurs along the concentration gradient, *i.e.*, from region of higher concentration to region of lower concentration provided the cell membrane is permeable to it. No energy expenditure takes place.

(b) **Facilitated Diffusion.** The diffusion of hydrophilic substances along the concentration gradient through fixed membrane transport protein without involving energy expenditure, is called **facilitated diffusion.** This diffusion is very specific as it allows cell to select substances for uptake. It is sensitive to inhibitors as well as show saturation effect. The membrane proteins taking part in facilitated diffusion are called **permeases.** Some permeases form channels for passage of selected solutes. Channel proteins allow diffusion of the solutes of an appropriate size may diffuse. Some proteins allow transport only if two types of molecules move together. This is called **cotransport**. It is of two types (Fig. 11.2). In **symport** method of **cotransport**, both molecules cross the membrane in the same direction at the same time. In **antiport** method of cotransport, both molecules move in opposite direction. When a molecule moves accross a membrane independent of other molecule, the process is called **uniport**.

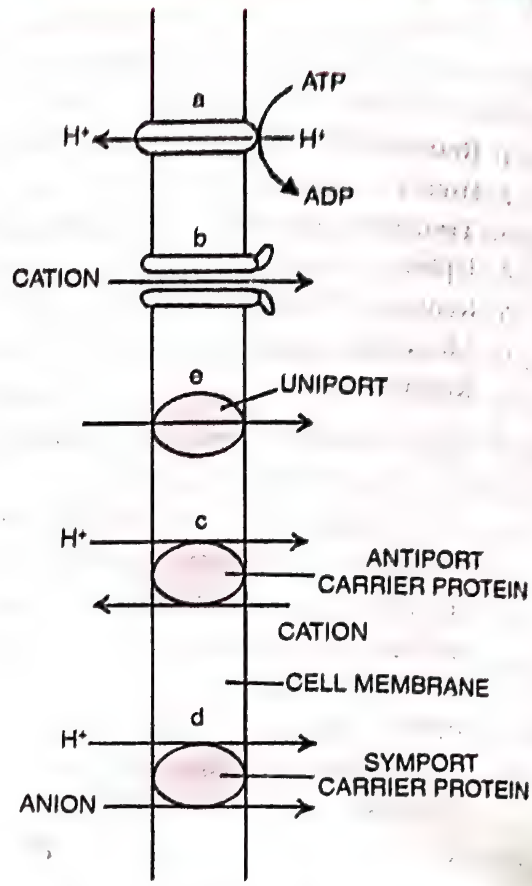


Fig. 11.2. Diagram showing activity of a membrane proton pump to solute exchange. (a) Proton pump using ATP to establish a proton gradient. (b) Ion channel activated by proton gradient. (c) Antiport carrier and (d) Symport carrier to drive the removal or uptake of ions from the cell. (e) Uniport carrier.

(c) **Ion channels** allow passage of their own specific ions. They are often gated— voltage gated, mechanical gated, ligand gated, temperature gated. The gates open under specific conditions, *e.g.*, K^+ channels in nerve conduction. Certain pores called **porins** are present in the outer membrane of plastids, mitochondria and some bacteria. They are large protein pores which allow even small sized proteins to pass through. Normally passage is allowed for only small sized particles. Passage of some important solutes is connected with the occurrence of transport or carrier proteins.

(d) **Active transport.** In **active transport**, the movable carrier proteins are called **pumps**. They employ ATP energy for transport across the membrane. It is uphill transport, *i.e.*, against concentration gradient and is faster than passive transport. The rate of active transport reaches the maximum when all the protein pumps are being used in transport (saturation effect). Carrier proteins are highly specific like enzymes. They are also sensitive to inhibitors that react with protein side chains. Active transport liberates energy which is used in transport of other solutes. The phenomenon is called **secondary active transport.**

Comparison of Different Transport Processes (Table 11.1)

Simple diffusion does not require the assistance of proteins for passage through the membrane. Both facilitated diffusion and active transport are mediated through membrane proteins. Active transport requires ATP energy. It is also uphill transport. Facilitated transport

does not require ATP energy. It usually occurs along the concentration gradient. The protein transporters of both facilitated diffusion and active transport are highly selective. They are liable to get saturated and respond to inhibitors as well as hormonal regulation.

Table 11.1. Comparison of Different Transport Mechanisms

Property	*Simple Diffusion*	*Facilitated Transport*	*Active Transport*
1. Requires Special Membrane Proteins	No	Yes	Yes
2. Highly Selective	No	Yes	Yes
3. Transport Saturates	No	Yes	Yes
4. Uphill Transport	No	No	Yes
5. Requires ATP Energy	No	No	Yes
6. Movement of Transport Proteins	No	No	Yes
7. Response to protein inhibitors	No	Yes	Yes

Differences between Diffusion and Facilitated Diffusion

Diffusion	*Facilitated Diffusion*
1. It is passage of particles from the area of higher concentration to the area of lower concentration, throughout the available space.	1. It is passage of particles from the area of higher concentration to the area of lower concentration through specific sites.
2. A number of different types of particles can diffuse simultaneously through the same space.	2. Only one type of particles can pass through its specific sites in facilitated diffusion.
3. It is a completely physical process.	3. It is a physical process that is dependent upon the availability of specific sites.

PLANT-WATER RELATIONS

Water is a major component of all living cells, a medium in which all substances are dissolved and undergo various types of reactions. Water is itself a reactant as well as a product. It is a medium for transport. Water is essential for cell growth and cell turgidity. Most herbaceous plants contain 85–90% water while Water Melon has 92% water. In trees and shrubs the woody parts have relatively lower amount of water while the softer parts have quite a large amount of it. A seed which appears dry has 10–15% water. Without this water, it will stop respiring and die.

The amount of water absorbed by a plant is very high. For example, a Maize or Corn plant absorbs about 3 litres of water per day while a Mustard plant would absorb water equal to its weight in just five hours. The amount of water absorbed by larger sized plants is very large, 36–45 litres in Apple and more than 1 tonne per day in Elm tree. Because of this huge requirement of water, it is often a limiting factor for plant growth and productivity both in agriculture and natural ecosystems.

IMBIBITION

The absorption of water by the solid particles of an adsorbent causing it to enormously increase in volume without forming a solution is called **imbibition**. Solid substances or

adsorbents which take part in imbibition are called **imbibants**, *e.g.*, seeds, dry wood. The liquid (usually water) which is imbibed is known as **imbibate**. The imbibate is held in between and over the surface of particles of the solid substance through the processes of **capillarity** and **adsorption**. Plant imbibants are **hydrophilic** (Gk. *hydor*— water, *philein*— to love) colloids. They have a highly negative water potential. As a result when they come in contact with water ($y_w = O$), a steep water potential gradient is established. Water diffuses rapidly into the adsorbent. The process will continue till an equilibrium is established. Amount of imbibition depends upon (i) Water potential gradient between adsorbent and water and (ii) Affinity of adsorbant for water. Imbibition increases the volume of the imbibant but the increase is less than the volume of water absorbed. It is caused by holding of water in between and over the surface of imbibant particles. Water molecules are immobilised. Their kinetic energy is released in the form of heat **(heat of wetting)**. The swelling imbibant also develops a pressure called **imbibition pressure** (matric potential). Air dried Pea seeds on coming in contact with water can develop an imbibition pressure of upto 1000 bars (= 100 MPa). This is tested by placing dry seeds in a tin, adding water upto their upper level and then tightly putting the lid over it. Within an hour the lid will be blown off. Alternately fill a gas jar ¾ with dry seeds. Pour water upto the brim. Cover the cylinder with lid and place a weight over the lid. Within a couple of hours the lid alongwith weight is lifted. Imbibition capacity is maximum in phycocolloids followed by proteins, starch and cellulose. Lignin is **hydrophobic**. It, therefore, does not show imbibition of water. Imbibition is influenced by a number of factors like texture (looseness more and compactness less imbibition) of the imbibant, temperature (rises with rise of temperature), pressure (decreases if pressure is against imbibant), electrolytes (decreases) and *p*H (decreases or increases depending upon charge of imbibant).

Imbibition plays an important role in absorbing and retaining water. (i) Absorption of water by young cells is mostly through imbibition. (ii) Water is absorbed by the germinating seeds through imbibition. (iii) Breaking of the seed coat in germinating seeds is due to greater imbibitional swelling of the seed kernel (starch and protein) as compared to seed coverings (cellulose). (iv) Seedling is able to come out of soil due to development of imbibition pressure. (v) Imbibition pressure developed during germination of seeds and spores can break asphalt roads and concrete pavements. (vi) Jamming of wooden frames during rains is caused by swelling of wood due to imbibition. (vii) In older times, it was used in breaking the rocks and boulders. Wooden pegs were inserted in rocks. They were then made wet. As a consequence the wooden pegs developed huge imbibition pressures that could break the rocks into pieces. (viii) Fruits of many plants come to develop matric potential in addition to their osmotic potential in order to maintain inflow of water even under conditions of water scarcity.

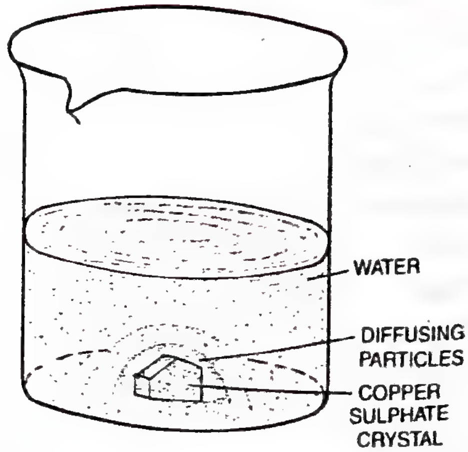


Fig. 11.3. Diffusion of copper sulphate from crystal in a beaker containing water.

DIFFUSION

The tendency on the part of molecules, atoms, ions, etc., of gases, liquids and solids to get evenly distributed throughout the available space on account of their **random kinetic motion** is called diffusion. Random kinetic motion of particles is due to kinetic energy present in them. Diffusion is also defined as the movement of the particles of different substances from the region of their

higher concentration, free energy or diffusion pressure to region of their low concentration, free energy or diffusion pressure. Diffusion is dependent upon the number of particles per unit volume, density of medium, distance through which diffusion is to occur, temperature and pressure. Diffusion will be more rapid when the difference in concentration is larger. Gases diffuse more rapidly than liquids. Solids are the slowest to diffuse. When the particles of diffusing substance get evenly distributed, a state of equilibrium is reached. It stops further movement.

Diffusion of particles of one substance is independent of the diffusion of particles of another substance, provided the two do not react. It is known as **independent diffusion.** The diffusion pressure of the individual substance is then known as **partial pressure.** Thus in photosynthesising leaf, water vapours and oxygen diffuse out while carbon dioxide enters the leaf depending upon the differences in their partial pressures in the leaf interior and the outside. Diffusion is also responsible for uptake and distribution of water and solutes.

(i) Open a bottle of perfume in one corner of room. Soon odour of the perfume will be felt throughout the room. (ii) Place a **crystal** of **copper sulphate** in a **beaker** containing **water**. An intense blue colour will be seen around the crystal. It decreases with the increase of distance from the crystal. It shows that copper sulphate molecules are diffusing into water (Fig. 11.3). Water molecules will also move towards copper sulphate crystal in order to occupy that space. Ultimately the molecules of the two, water and copper sulphate, will be evenly distributed throughout the solution.

Diffusion Pressure (D.P.). The pressure exerted by the tendency of the particles to diffuse from the area of its higher concentration to the region of its lower concentration is called diffusion pressure. It is proportional to the concentration of diffusing particles. A porous pot is fitted to a glass tube, one end of which dips in water. A gas jar filled with hydrogen is inverted over the porous pot. Hydrogen has the ability to diffuse more rapidly into porous pot than the ability of air to diffuse out of the porous pot. This develops a pressure inside the porous pot which pushes the air from the tip of glass tube into water in the form of air bubbles (Fig. 11.4).

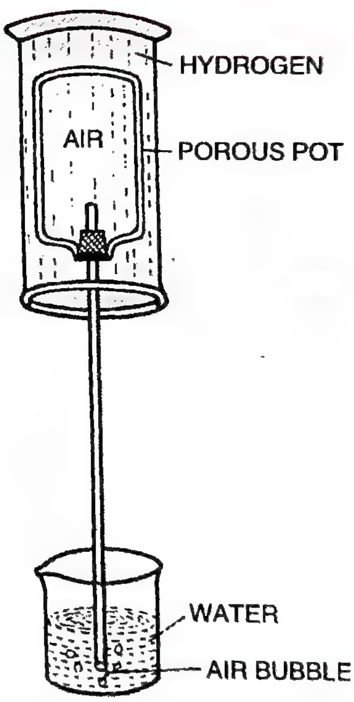


Fig. 11.4. Demonstration of Diffusion Pressure.

Factors Influencing Diffusion. (i) **Density**. Rate of diffusion of a substance is inversely proportional to square root of its relative density (Graham's Law). (ii) **Permeability of Medium.** Rate of diffusion decreases with density of the medium. (iii) **Temperature.** A rise in temperature increases the rate of diffusion with Q_{10} = 1·2–1·3. Because of it sugar crystals do not dissolve easily in ice cold water while they do so easily in warm water. (iv) **Diffusion Pressure Gradient.** Rate of diffusion is directly proportional to the difference of diffusion pressure at the two ends of a system and inversely proportional to the distance between the two.

Importance. (i) Diffusion keeps the cell walls of the internal plant tissues moist. (ii) It is a means of spreading of ions and other substances throughout the protoplast. (iii) Transpiration or loss of water in vapour forms is a diffusion process. (iv) Exchange of gases (CO_2 and O_2) between the plant interior and outside air occurs through diffusion. (v) Osmosis is a special type of diffusion in which water diffuses through a semi-permeable membrane. (vi) Aroma of flowers is due to diffusion of volatile aromatic compounds to attract pollinating animals.

Differences between Diffusion and Imbibition	
Diffusion	*Imbibition*
1. It is movement of substances from the region of their higher concentration to the region of lower concentration.	1. It is absorption of water by the particles of a solid without forming a solution.
2. An adsorbent is absent.	2. Imbibition only occurs when an adsorbent (=imbibant) is present.
3. All the substances present in the medium show diffusion.	3. Only the liquid diffuses. The solid particles do not diffuse.
4. There is little change in pressure.	4. A very high pressure develops on imbibition
5. Energy is not liberated.	5. Heat is liberated during imbibition.
6. There is no change in volume.	6. The imbibant swells up but the swelling is less than volume of imbibate.

Membrane Permeability

Membrane permeability is the ability of a membrane to allow passage of gases, liquids, solutes (dissolved substances) through it. It is dependent upon two factors—nature of membrane (membrane composition) and nature of passing substance. Permeability of a membrane is measured by determining the rate of passage of a substance through it under specific standard set of conditions. On the basis of their permeability, membranes are of four types — impermeable, permeable, semipermeable and selectively permeable. **Impermeable membranes** do not allow the passage of substances (gases, solvent, solute) through them, *e.g.*, suberised cell walls, cutinised cell walls. **Permeable membranes** allow the passage of substances through them, *e.g.*, cellulose cell walls. **Semipermeable membranes** are those membranes which permit the movement of solvent molecules through them but prevent the movement of solute particles, *e.g.*, egg membrane, animal bladder, parchment membrane. Selectively or **differentially permeable membranes** are normally semipermeable but allow selective passage of solutes through them, *e.g.*, plasmalemma (plasma membrane), tonoplast.

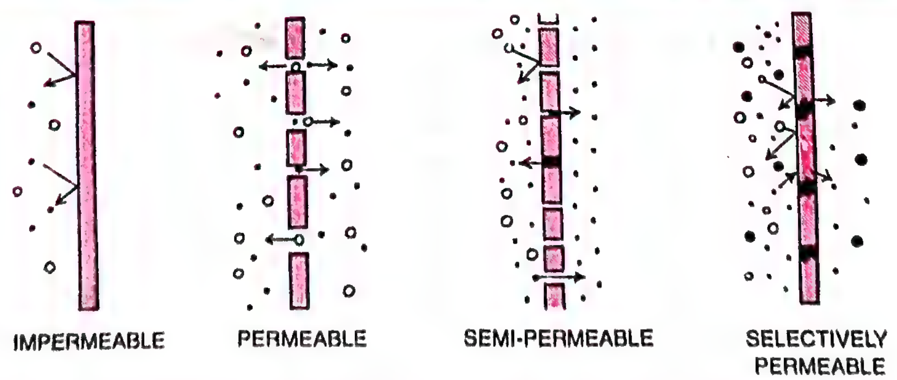


Fig. 11.5. Types of membranes on the basis of their permeability.

Differences between Semipermeable and Selectively Permeable Membranes	
Semipermeable Membrane	*Selectively Permeable Membrane*
1. It does not allow passage of solutes through it.	1. It allows passage of some selected solutes to a limited extent.

2. It forms a perfect partition between two osmotically active solutions or between a solution and its pure solvent.	2. The partition is imperfect because of which even plasmolysed protoplasts get deplasmolysed automatically even when kept in the same hypertonic solution.
3. It allows entry of only solvent.	3. It allows entry of both solvent and to a selected extent solutes.
4. It is not found in biological world. *e.g.*, collodion, cellophane.	4. Almost all biological membranes are selectively permeable.
5. Semipermeable, membrane is used in dialysis, maintenance of turgidity and measurement of osmotic potential.	5. Selectively permeable membrane is useful in maintaining turgidity while retaining the ability to absorb solutes.

OSMOSIS

Osmosis is a special type of diffusion of water that occurs through a semipermeable membrane.

Definition of Osmosis. (i) Diffusion of water from its pure state or dilute solution into a solution or stronger solution when the two are separated by a semipermeable membrane is termed as osmosis.

(ii) The movement of water from its higher chemical potential (found in pure state or dilute solution) to its lower chemical potential (found in solution or stronger solution) without allowing the diffusion of solute by means of a semipermeable membrane is called osmosis. The chemical potential of water is also called **water potential.**

(iii) Osmosis is movement of solvent or water molecules from the region of their higher diffusion pressure or free energy to the region of their lower diffusion pressure or free energy across a semipermeable membrane.

The direction and rate of osmosis depend upon the sum of two forces, pressure gradient (gradient of Ψ_p) and concentration gradient (gradient of Ψ_s). The net force or gradient is determined by the difference in the water potentials of solutions separated by a semipermeable membrane. A solution which can cause an osmotic entry of water into it is said to be **osmotically active solution**. It possesses a low water potential. Diffusion of water into it will continue across the separating membrane till an equilibrium is reached. At equilibrium water potential becomes equal on both sides of the membrane.

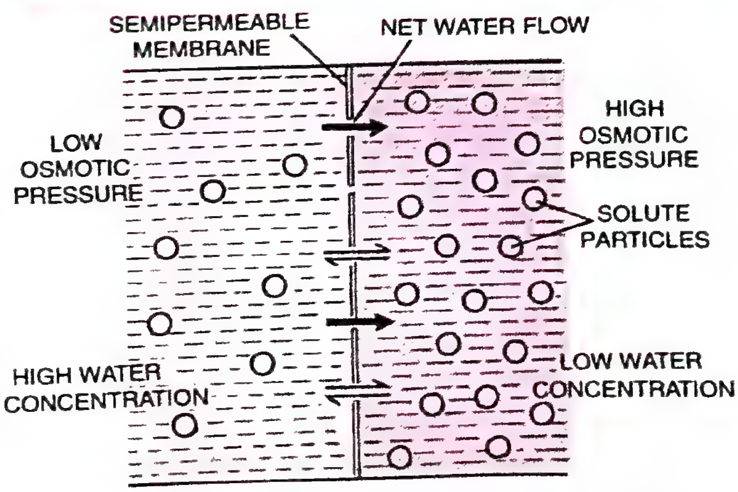


Fig. 11.6. Net movement of water from its higher chemical potential (dilute solution) to lower chemical potential (concentrated solution) when the two are separated by a semipermeable membrane.

Explanation. Solute particles decrease the chemical potential of water by decreasing the mole fraction of water. In osmosis, a semipermeable membrane separates (say) dilute solution A and concentrated solution B. Solute particles cannot pass through the semipermeable membrane. Water molecules are in random motion. They strike the semipermeable membrane on both the sides and pass through the same (Fig. 11.6). Since more free water molecules are present on the side of dilute solution A, more of them pass through the membrane to enter the

solution B as compared to the reverse flow. There is, therefore, a net diffusion of water from its higher chemical potential (dilute potential) to its lower chemical potential (concentrated solution).

Types of Osmosis. Osmosis is of two types— (i) **endosmosis**— the osmotic entry of water into a cell, organ or system (ii) **exosmosis**— the osmotic withdrawal of water from a cell, organ or system.

Demonstration of Osmosis

Expt. 1. Thistle Funnel Experiment

Apparatus. 10% sugar solution, a long stemmed thistle funnel, animal bladder, egg membrane or parchment paper, thread, scissors, rubber solution, beaker, water, glass marking pencil or gummed paper and stand. Egg membrane is prepared by first removing the yolk and albumin of the egg through a small hole at one end. The egg shell with membrane is then placed in dilute hydrochloric acid for a few hours when the shell will dissolve. The egg membrane is left intact.

Working. Take a thistle funnel having a long stem. Close the mouth of the funnel with a membrane of animal bladder or parchment paper by means of thread. Remove the free edges of the membrane with the help of scissors as close to thread as possible. The terminal edges of the membrane are then sealed by applying rubber solution. This makes the joint water tight.

Pour 10% sugar solution in the thistle funnel till it stands at about 1/3 of the height of the stem. Now dip the covered end of the thistle funnel in a beaker containing water (Fig. 11.7). Support it in its position by means of a stand. Mark the level of sugar solution as A by means of glass marking pencil or gummed paper. Note that after a few minutes the level of the sugar solution has risen in the stem of thistle funnel to a point B while the level of water falls down in the beaker. Taste the water of the beaker. It is not sweet.

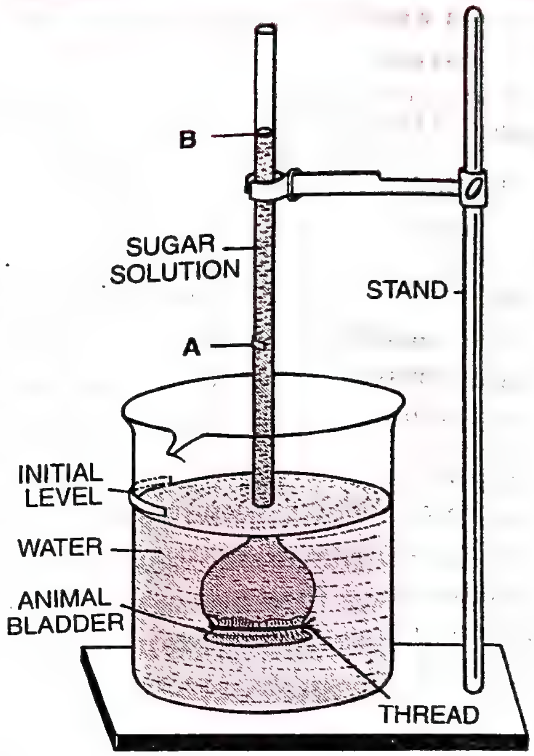


Fig. 11.7. Thistle funnel experiment to demonstrate osmosis.

Results. The rise of sugar solution in thistle funnel can only be due to the entry of water into it through the animal bladder. But no sugar has gone out into the water of the beaker as it does not taste sweet. The experiment, therefore, proves that :

(i) Animal bladder, egg membrane or parchment paper is a **semipermeable membrane** because it allows only water to pass through it. (ii) Sugar solution is an **osmotically active** solution and can absorb water when it is separated from it by a semipermeable membrane. (iii) Water diffuses into a solution when the two are separated by a semipermeable membrane. The phenomenon is called **osmosis**.

Precautions. (i) The edges of the animal bladder must be properly sealed. (ii) The thread should be tied carefully so as not to rupture the membrane. (iii) The initial level of sugar solution should be marked only after dipping the mouth of thistle funnel inside water of the beaker. (iv) Pour sugar solution in the thistle funnel in such a way as not to leave any air bubble. (v) Support and fix the thistle funnel firmly in its vertical position by means of a stand.

Expt. 2. Potato Osmoscope

Apparatus. A large potato, a knife or scalpel, 20% sugar solution, petri dish containing water, two pins.

Working. Take a large sized potato tuber. Cut one side of it so as to make it flat. Bore a cavity from the other side in such a way that a very thin base is left intact on the flat side. Also remove the skin near the edge of the flat end because skin of the tuber is impermeable to water.

Pour 20% sugar solution in the cavity of the tuber up to ½ – ¾. Mark the level of sugar solution in the cavity with the help of a pin (Fig. 11.8 A). Place the tuber on its flat cut end in a petri dish half full of

water. Note that after some time the level of the sugar solution has risen in the cavity. Mark this reading also with another pin (Fig. 11.8 B).

Results. The rise in the level of sugar solution in the cavity of the potato tuber indicates that the solution has absorbed water from the petri dish. The two are separated from each other by a large number of cells of the tuber. The entry of water into the sugar solution, therefore, proves that : (i) Sugar solution is **osmotically active** solution. (ii) The cytoplasm of the cells of the tuber that lie between the sugar solution and the water of the petri dish act as a single **semipermeable membrane**. (iii) Water enters the sugar solution when it is separated from it by semi-permeable membrane. This process is called **osmosis**.

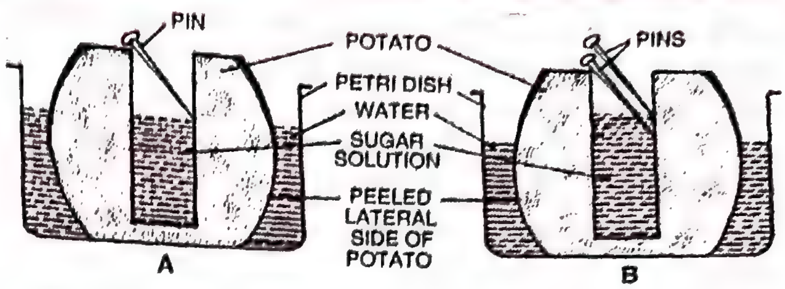


Fig. 11.8. Potato osmoscope experiment to demonstrate osmosis. A, Original level; B, Final level.

Precautions. (i) The cavity should be deep so as to leave only a thin layer of tissue at the base. (ii) Peel off the skin of the tuber from the base and the sides. (iii) Make the base flat so as to keep the tuber flat in the dish. (iv) Sugar solution should have a higher osmotic concentration as compared to cell sap of the tuber cells.

Expt. 3. Demonstration of Endomosis and Exosmosis

Apparatus. A few grapes and raisins with intact stalks, water, 10% salt solution, petri dishes.

Place a few raisins in water for about 5–6 hours. Raisins will swell up. The swelling can be due to the absorption of water from the petridish.

In another petri dish place a few fresh grapes, (or swollen raisins) and pour 10% salt solution into the dish. After a few hours the grapes will shrivel which can be possible only when they have lost water to the salt solution (Fig. 11.9).

In the first case the raisins have absorbed water from the outside due to the presence of higher concentration of solute in them. This is an example of **endosmosis**. In the second case, the grapes have lost water to the salt solution because salt solution is more concentrated than the sap present in grapes. Therefore, it is an example of **exosmosis**.

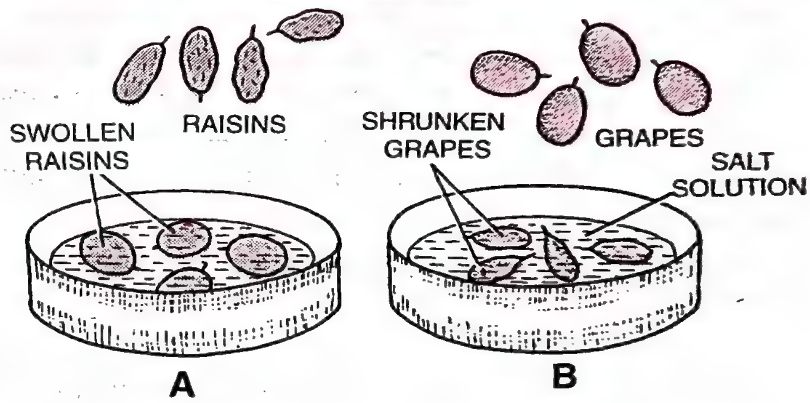


Fig. 11.9. Experiment to demonstrate endosmosis in raisins and exosmosis in grapes.

Precautions. (i) Grapes and raisins should be with intact stalks. (ii) The solution for exosmosis must be stronger than sap concentration of grapes.

Osmotic Pressure (O.P.)

It is maximum pressure which can develop in an osmotically active solution when it is separated from its pure solvent by a semipermeable membrane under ideal conditions of osmosis that do not allow dilution of solution. Osmotic pressure is also defined as the pressure required to completely stop the entry of water into an osmotically active solution across a semipermeable membrane (Fig. 11.10). It is measured in atmospheres, bars or pascals*. Osmotic pressure is numerically equal to osmotic potential (= solute, potential, ψ_s) but while osmotic potential has a negative value, osmotic pressure (π, pi) has a positive value, ($\psi_s = -\pi$). The instrument used for measuring osmotic pressure is called **osmometer**, *e.g.*, Berkeley and Hartley's osmometer, Pfeffer's osmometer.

* 1 bar = 0.987 atm = 10^5 pascals (Pa) = 0.1 Megapascal (MPa).

Aquatic plants have an osmotic pressure of 1–3 atm, mesophytes 5–15 atm while in xerophytes it lies between 10–30 atm but goes upto 60 atm under drought conditions. Upper leaves have more osmotic pressure than the lower leaves. Seeds may develop an osmotic pressure of 100 atm. Halophytes have the maximum osmotic pressure with *Atriplex confertifolia* showing an O.P. of 202. 4 atm (Harris, 1934).

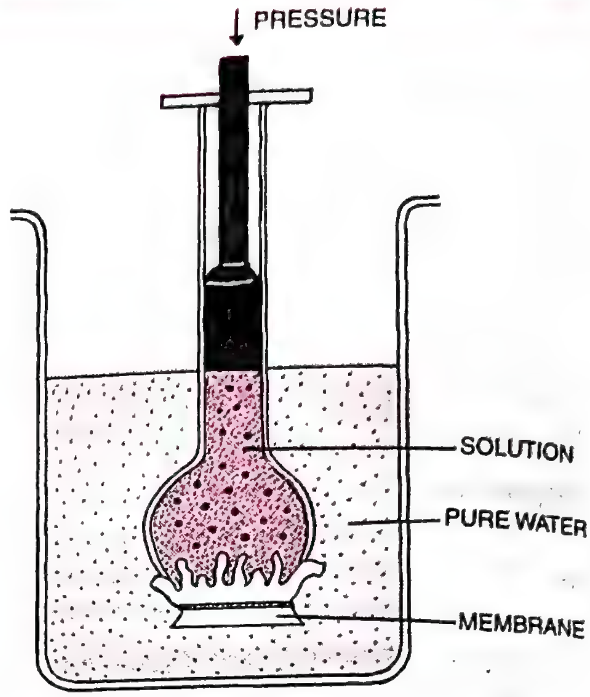


Fig. 11.10. Measurement of osmotic pressure of a solution.

Reverse Osmosis. It is the expulsion of pure water from a solution through a semipermeable membrane under the influence of pressure higher than the O.P. of the solution. Reverse osmosis is used in removing salts from saline water as well as extra-purification of water.

Factors Controlling Osmosis. Presence of a perfectly semipermeable membrane is a must for the operation of osmosis. Osmosis is driven by two other factors; (i) Concentration of dissolved solute on the two sides of semipermeable membrane. (ii) Difference in pressure. In thistle funnel experiment there is no indefinite passage of water from beaker into the funnel despite the fact that osmotic potential of the solution continues to be negative as compared to the chemical potential of pure water. It is because after some distance the raised column of solution exerts sufficient pressure over the semipermeable membrane as to balance the chemical potential of pure water.

Osmotic Concentrations. A solution having low osmotic concentration (hence low osmotic pressure but less negative solute potential) as compared to another solution is known as **hypotonic solution**. A solution having high osmotic concentration (hence high osmotic pressure but more negative solute potential) as compared to another solution is termed as **hypertonic solution**. The two solutions with the same concentration or pressure or potential are named as **isotonic solutions**. External hypotonic solution will cause endosmosis while hypertonic solution results in exosmosis. There is no change if the external solution is isotonic (Fig. 11.11). Such a **flaccid** cell will allow movement of water in both the directions.

Differences between Hypotonic and Hypertonic Solutions

Hypotonic Solution	*Hypertonic Solution*
1. It is a solution which is more dilute as compared to another solution.	1. It is a solution which is more concentrated as compared to another solution.
2. The osmotic potential is higher, *i.e.*, less negative.	2. The osmotic potential is lower, *i.e.*, more negative.
3. Cell placed in hypotonic solution will swell up.	3. Cells placed in hypertonic solution will undergo plasmolysis.

Differences between Turgid and Flaccid Cells

Turgid Cell	*Flaccid Cell*
1. There is endosmosis or entry of water into a cell.	1. The cell does not undergo endosmosis.
2. Turgor pressure increases.	2. There is no increase in turgor pressure.
3. The cell swells up.	3. There is no swelling as equal amounts of water pass in and pass out of the cell.

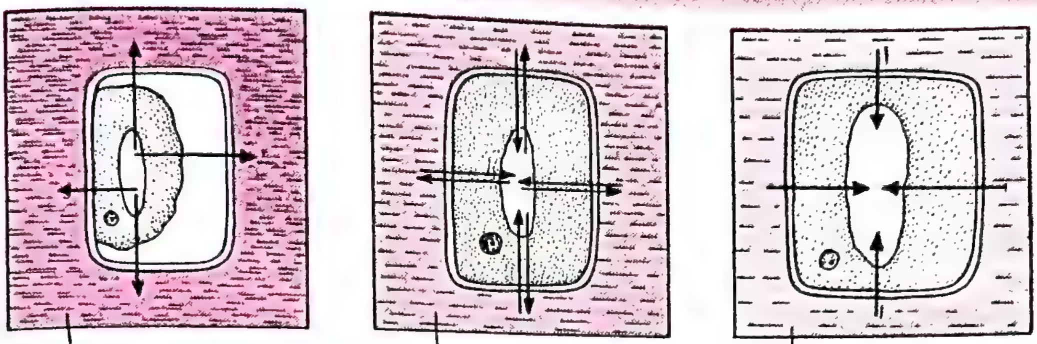


Fig. 11.11. Behaviour of a living cell placed in solutions of different concentrations.

Importance of Osmosis

(1) Entry of soil water into root is carried out by osmosis. (2) Osmosis performs cell to cell movement of water. (3) Living cells remain distended or turgid only by the osmotic entry of water into them. (4) Various cell organelles like mitochondria and chloroplasts will collapse if they are not able to maintain a proper osmotic concentration. (5) 70% of cell water is held in vacuoles. It has come from outside through endosmosis and is kept in its place due to osmotic concentration of solutes dissolved in it. (6) The soft organs like leaves, flowers, fruits and young stems are able to keep themselves stretched and swollen due to turgidity of their cells which is dependent upon osmosis. (7) Osmosis plays a key role in the growth of radicle and plumule during the germination of seeds. (8) Many plant movements like the folding and drooping of leaves in *Mimosa* are brought about by osmosis. (9) The stomata open and close only in response to increase or decrease of the osmotic pressure of the guard cells in relation to nearby epidermal cells. (10) A high osmotic pressure has been found to protect the plants against drought and frost injury. Seeds and spores are similarly able to pass through the unfavourable periods due to high osmotic pressure (or low solute potential).

Differences between Diffusion and Osmosis

Diffusion	*Osmosis*
1. It is the movement of all types of substances from the area of their higher free energy to the area of their lower free energy.	1. It is the movement of only solvent or water from its higher free energy or chemical potential to the area of its lower chemical potential when the solute particles are not allowed to diffuse.
2. Diffusion can operate in any medium.	2. Osmosis operates only in a liquid medium.
3. Diffusion is applicable to all types of substances— solids, liquids or gases.	3. It is applicable to only solvent part of a solution.
4. It does not require any semipermeable membrane.	4. A semipermeable membrane is a must for the operation of osmosis.
5. It is purely dependent upon the free energy of the diffusing substance.	5. Osmosis is dependent upon the degree of reduction of free energy of one solvent over that of another.
6. It helps in equalising the concentration of the diffusing substance throughout the available space.	6. It does not equalise the concentration of solvent on the two sides of the system.
7. Hydrostatic or turgor pressure does not normally operate in diffusion.	7. Osmosis is opposed by turgor or hydrostatic pressure of the system.
8. It is not influenced by solute potential.	8. Osmosis is dependent upon solute potential.
9. Diffusion of a substance is largely independent of the presence of other substances.	9. Osmosis is dependent upon the number of particles of other substances dissolved in liquid.

Differences between Imbibition and Osmosis

Imbibition	*Osmosis*
1. It involves the absorption of solvent or water by a solid substance.	1. It involves the movement of water or solvent from its higher chemical potential to lower chemical potential.
2. A semi-permeable membrane is not required.	2. A semi-permeable membrane is essential for the operation of osmosis.
3. Imbibition does not produce a solution.	3. Osmosis usually operates in solutions separated by semipermeable membrane.
4. It produces heat.	4. Heat is not produced.
5. It can develop a very high pressure (upto 1000 atm) called imbibition pressure.	5. Osmosis develops a comparatively lower pressure (upto 100 atm) known as osmotic pressure.
6. Imbibition requires the presence of colloidal particles.	6. Osmosis usually requires the presence of solute particles.

Diffusion Pressure Deficit (DPD; Meyer, 1938)

It is an older term that was used in place of water potential. Pure water has the **maximum diffusion pressure**. Its diffusion pressure gets lowered by the addition of solute particles in it. *The reduction in the diffusion pressure of water in a solution over its pure state is called diffusion pressure deficit* or DPD. Because of the presence of diffusion pressure deficit, a solution will always tend to make up the deficit by absorbing water. Diffusion pressure deficit is also called **suction pressure**. Its value is equal to the osmotic pressure or potential (positive value taken in bars or atm) of the solution in a cell or system minus the wall pressure (= turgor pressure) which opposes the entry of water into it provided the external water is pure.

$$DPD = OP - WP\ (= TP)$$

In case the external fluid is a solution the value of DPD will be equal to the difference in osmotic pressures of cell solution (OP_1) and external solution (OP_2) minus the wall pressure.

$$DPD = (OP_1 - OP_2) - WP\ (= TP)$$

WATER POTENTIAL (Slatyer and Taylor, 1960)

It is the difference in the free energy or chemical potential per unit molal volume of water in a system and that of pure water at the same temperature and pressure. Chemical potential of pure water at normal temperature and pressure is zero. In solutions the value of water potential is always negative or less than zero. It is represented by greek letter ψ (psi) or more accurately ψ_w. The value of ψ_w is measured in bars, pascals or atmospheres. Water always moves from the area of high water potential or high energy to the area of low water potential or low energy, *i.e.*, from less negative potential (*e.g.*, –1000 KPa) to more negative potential (*e.g.*, –2000 KPa). If two systems having water are in contact, more random movement of water molecules in the system having higher water potential or more energy will result in their net movement towards the system with low energy or low water potential, *e.g.*, soil and air, cell and solution. The movement of a substance from an area of higher free energy to area of lower free energy is called **diffusion**.

Water potential or ψ_w is the sum total of ψ_s and ψ_p.

$$\psi_w = \psi_s + \psi_p$$

ψ_s designates the effect of solute on the free energy of water while ψ_p indicates the effect of pressure on the same. However, another force which has a negative value and which decreases the water potential is matric potential (ψ_m). It is reduction in free energy of water when the latter comes to form thin surface layers adsorbed over colloidal particles. It is appreciable in case of dry seeds, young cells and dry soils. However, in case of mature cells and hydrated cell walls the effect of matric potential is negligible.

Differences between Diffusion Pressure Deficit (DPD) and Water Potential (Ψw)

Diffusion Pressure Deficit (DPD)	*Water Potential (Ψw)*
1. It is an old term coined by Meyer (1938) which is synonym with water potential.	1. It is modern term coined by Slatyer and Taylor (1960) which is equivalent to DPD.
2. It has positive value, *e.g.*, 5 atm.	2. It has a negative value *e.g.*, –5 atm.
3. Diffusion pressure deficit is the reduction in diffusion pressure of solvent in a system over its pure state.	3. Water potential is reduction in free energy of solvent in a system over its pure state.
4. Water is absorbed by a system having higher DPD from another system with lower DPD.	4. Water is absorbed by a system with lower Ψw from another system with higher Ψw.
5. DPD = OP – TP where all the terms are with positive values.	5. $\Psi w = \Psi s + \Psi p$ where Ψs has a negative value while Ψp has a positive value.
6. Matric pressure or imbibitional force is not considered.	6. Matric potential or Ψm is considered wherever it is appreciable.

Osmotic or Solute Potential (ψ_s). It is the decrease in the chemical potential of pure water due to the presence of solute particles in it. It is a colligative property of solute and is dependent upon the number of solute particles and not upon the nature of solute. Solute particles reduce the free energy of water by diluting it, increasing entropy, reducing vapour pressure, raising boiling point and lowering freezing point. Its value is calculated by the following formula

$$OP \text{ or } SP = C \times R \times T$$

where C is the concentration of solute particles in moles per litre (one mole or molecular weight in grams = 6.02×10^{23} particles or molecules), R is gas constant with a value of 0.083 (0.082 if in atmospheres) and T is the temperature in absolute degrees.

Thus osmotic potential of a molar solution of a nonelectrolyte like sucrose at 0°C or 273°A and 20°C or 293°A can be calculated as below :

at 0°C =1 × 0.083 × 273 =22.7 bars or 22.4 atm (as negative)

at 20°C =1 × 0.083 × 293 =24.3 bars or 24 atm. (as negative)

In case of electrolytes, the degree of ionisation is taken into consideration because osmotic or solute potential depends upon the number of particles (here as ions and molecules) and not upon the number of molecules alone. In case of strong electrolytes the osmotic potential may be almost double or triple as compared to nonelectrolytes. For example, 0.1N sucrose solution has an osmotic potential of –2.3 bars while 0.1N sodium chloride solution has ψ_s value of –4.5 bars.

Differences between Osmotic Pressure and Osmotic Potential

Osmotic Pressure	*Osmotic Potential*
1. It is the pressure which develops in an osmotic system due to entry of water into it.	1. It is lowering of free energy of water in a system due to the presence of solute particles.
2. It develops only in a confined system.	2. Osmotic potential is present whether the solution occurs in a confined system or an open system.
3. The value is positive though numerically equal to osmotic potential.	3. The value is negative though it is numerically equal to osmotic pressure.

Differences between Osmotic Potential and Matric Potential

Osmotic Potential	*Matric Potential*
1. It is reduction in free energy of water due to decrease in number of water molecules per molal volume.	1. It is reduction in free energy of water due to formation of thin immobile surface layers of water molecules.
2. Osmotic potential is caused by the presence of solute particles.	2. Matric potential is caused by adsorbant or colloidal particles.
3. It is important in water relations of plant cells.	3. It is unimportant in water relations of mature plant cells though essential for seed germination, early seedling growth and growth of developing fruits.
4. The value is rarely more than 0.5 – 2.0 MPa.	4. The value is 50 – 200 MPa.

Pressure Potential (ψ_p) or Hydrostatic Pressure

It is the pressure which develops in an osmotic system due to osmotic entry or exit of water from it. A positive pressure develops in a plant cell or system due to entry of water into it. Positive hydrostatic pressure is also called **turgor pressure**. Loss of water produces a **negative hydrostatic pressure** or **tension**. It develops in xylem due to loss of water in transpiration. This is very important in transport of sap over long distances in plants.

Positive hydrostatic pressure or *turgor pressure is the pressure which develops in the confined part of an osmotic system due to osmotic entry of water into it*. Due to turgor pressure the protoplast of a plant cell will press the cell wall to the outside. The cell wall, being elastic, presses the protoplast with an equal and opposite force. *The force exerted by the cell wall over the protoplast is called wall pressure* (WP). Normally wall pressure is equal and opposite to turgor pressure except when the cell becomes flaccid. The values of these two opposing forces continue to rise till the cell becomes fully swollen or **turgid**. At this time the value of wall or turgor pressure becomes equal to osmotic potential, $\psi_p = \psi_s$.

Turgor pressure has number of important functions :

(i) It keeps the cells and their organelles stretched. This is essential for proper functioning of a cell.

(ii) It provides support to nonwoody tissues like parenchyma.

(iii) Turgor pressure is essential for cell enlargement during growth.

(iv) It keeps the leaves fully expanded and properly oriented to light. Flowers, young stems and other softer organs are able to maintain their form due to turgidity or TP. In case of loss of turgidity, the shoots droop down and the leaves show wilting. Wilting is observed

in many plants during summer noon. In wilting the individual cells of leaves and other softer parts become flaccid due to loss of water from their interior. Plants gain their turgidity during night because of continued absorption of water from the soil. If the soil does not obtain water periodically (*i.e.*, the soil is deficient in water), the recovery may be only partial or it may not occur at all. The latter condition is known as **permanent wilting.** The plants are soon killed. Temporary wilting reduces growth and decreases the yield of plant.

(v) Many plant movements are produced due to reversible turgor changes in the cells. Sleep movements (nyctinasty) of bean leaves and shock movements (seismonasty) of Sensitive Plant (*Mimosa pudica*) are produced due to turgor changes in the cells of their pulvini. Regular turgor changes in the leaflet bases cause rhythmic autonomic jerky movements in the lateral leaflets of Indian Telegraph Plant, *Desmodium gyrans* (Fig. 11.12).

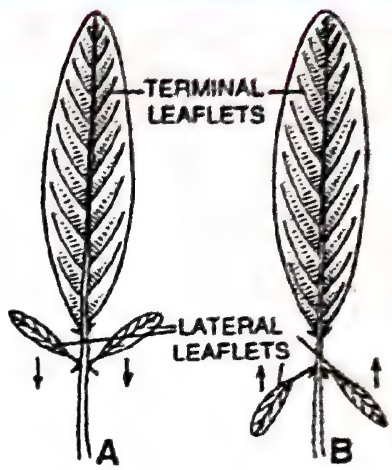


Fig. 11.12. Autonomic curvature movement of variation (turgor movement) in the two lateral leaflets of *Desmodium gyrans*.

(vi) The opening and closing of stomata are caused by gain and loss of turgidity by their guard cells. They are hence often called "turgor operated valves."

(vii) Turgor pressure (pressure potential or hydrostatic pressure) keeps a check on the excessive entry of water into cells.

(viii) Autochory of some fruits is dependent upon release of turgor pressure.

Osmotic Relations of Plant Cells (Fig. 11.13)

A plant cell functions as an osmotic apparatus or osmotic system. It is bathed in a water medium or lies in contact with other cells having water. A typical plant cell has a permeable elastic wall, a semipermeable membrane (plasmalemma or plasma membrane alone or alongwith cytoplasm and tonoplast) and an osmotically active solution called **cell sap** (contained in the central vacuole). The osmotically active cell sap has an osmotic potential (ψ_s or OP). It causes the osmotic entry of water which develops a turgor pressure (TP) or pressure potential (ψ_p). The osmotic status of the cell is written as, $\psi_w = \psi_s + \psi_p$ or DPD = OP – TP (= WP). ψ_s or solute potential is a negative force. It causes entry of water into the cell.

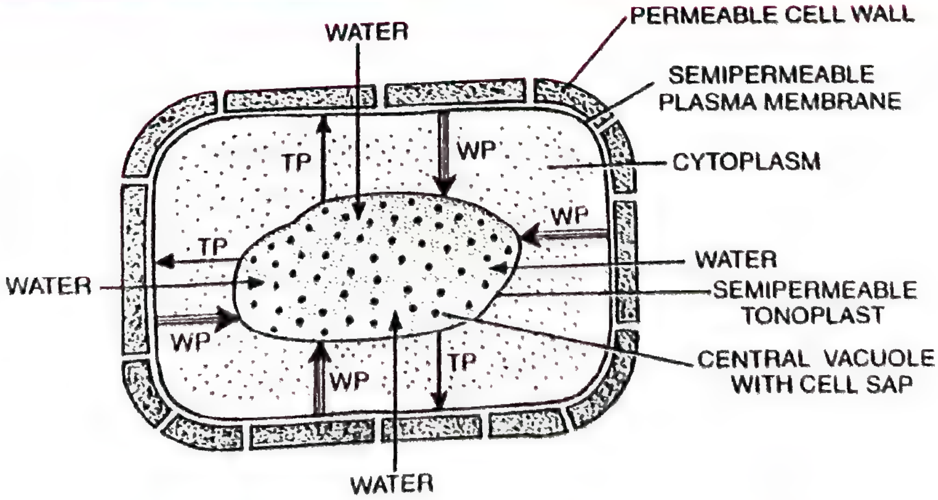


Fig. 11.13. Plant cell as an osmotic system.

As a result a cell protoplast swells and develops the positive force of ψ_p. ψ_p is kept under check by **wall pressure**. The cell where wall is absent cannot counteract pressure potential. It will continue to absorb water due to ψ_s till it bursts. It is because of this fact that the animal cells are not bathed in water but instead are surrounded by nearly isotonic tissue fluid.

Being a positive force, ψ_p opposes the entry of water into the cell.

(a) **Rise in Turgidity**. A flaccid cell placed in hypotonic solution will absorb water. The cell swells up. The value of turgor pressure rises while that of sòlute potential becomes slightly less negative. As the cell becomes fully turgid, the value of turgor pressure becomes equal to that of sòlute potential (ψ_s) so that water potential (ψ_w) or DPD becomes either zero or equal to that of external hypotonic solution.

$$\psi_w = \psi_s + \psi_p = 0$$

Though there is no net movement of water between the cell and its environment, equilibrium is dynamic and not static. Equal exchange of water molecules continues between the cell and its environment.

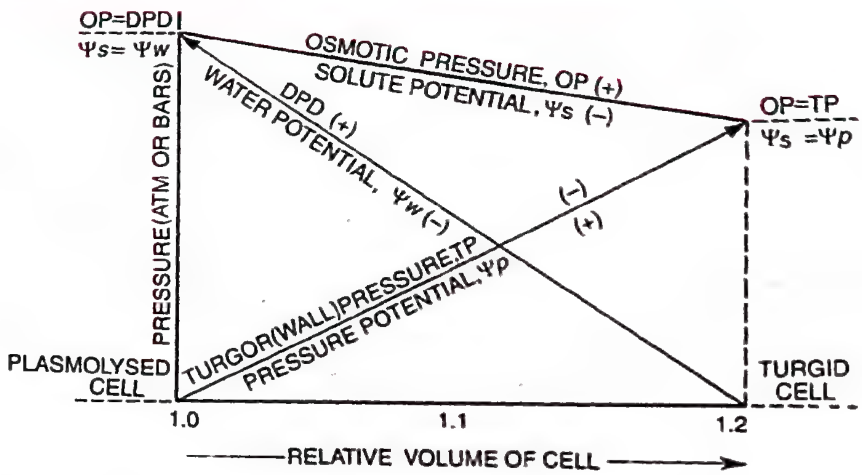


Fig. 11.14. Relationship between OP (= ψ_s), TP (= WP or ψ_p) and DPD (= ψ_w) of a cell. Note that DPD ($-\psi_w$) is zero when TP (ψ_p) becomes equivalent to OP (= ψ_s) while DPD (= ψ_w) becomes equal to OP (ψ_s) when TP (= ψ_p) is nil as in a plasmolysed cell.

(b) **Loss of Turgidity**. If plant cell happens to be bathed in hypertonic solution, it loses water through the process of exosmosis. The loss of water is first from cytoplasm and then central vacuole. As a result, the protoplast is reduced in size. This decreases turgor pressure or pressure potential and corresponding wall pressure. Solute potential becomes slightly more negative due to loss of water. The cell attains a minimum size when turgor pressure is zero. If the external solution does not cause any further exosmosis, the value of its solute potential will be equal or isotonic to solute potential of the cell.

$$\psi_w = \psi_s + \psi_p \text{ or } \psi_w = \psi_s$$

A cell which is deficient in turgor is called **flaccid**. A flaccid cell kept in isotonic solution will show equal flow of water into and out of the cell.

In case exosmosis continues, the protoplast shrinks from the cell wall. The phenomenon is called **plasmolysis**.

(c) **Water Relations between Adjacent Cells** (Fig. 11.15). Cells gain or lose water among themselves on the basis of their water potential (or DPD) and not their solute or osmotic potentials. A cell having more negative osmotic potential and high turgor pressure can lose water to a cell having less negative osmotic potential provided it has still lower turgor pressure.

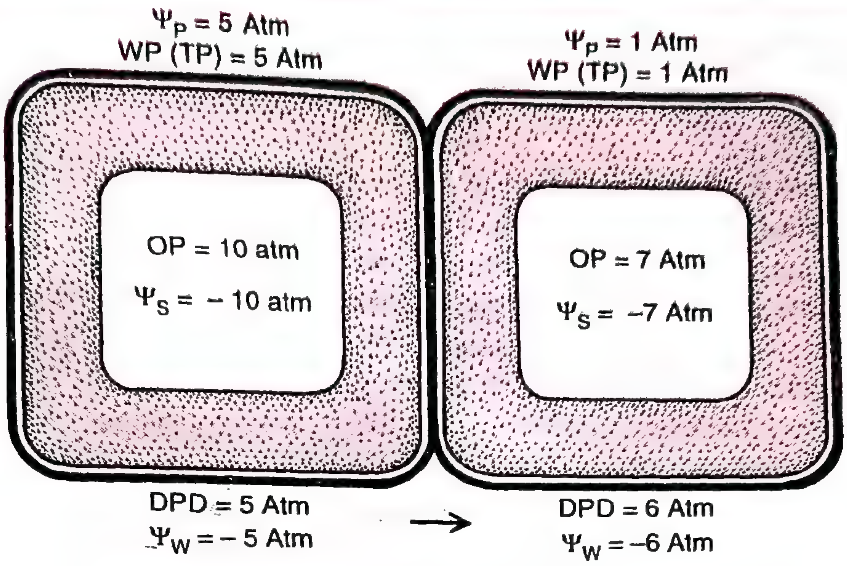


Fig. 11.15. Development of higher DPD (lower ψ_w) in a cell having lower OP (comparatively higher ψ_s) due to reduced TP (ψ_p) or WP.

Differences amongst OP (Ψs), TP (Ψp), WP and DPD (Ψw)

OP = ψ_s	*TP = ψ_p*	*WP*	*DPD = Ψ_w*
1. It is potential pressure that can develop in a solution when it is separated from pure solvent by a semipermeable membrane.	1. It is hydrostatic pressure which develops in a system due to osmotic entry of solvent in it.	1. It is the force exerted by the wall against expansion of osmotic system.	1. It is reduction in diffusion pressure or free energy of a solvent in an osmotic system over pure solvent.
2. It can develop in both confined and unconfined systems.	2. It develops only in a confined system.	2. Wall pressure occurs in a confined system.	2. It is found both in confined and unconfined systems.
3. It is dependent upon the number of solute particles in the solution.	3. It is dependent upon the amount of water that enters a confined system.	3. It is the resistance, the wall holds over the expanding osmotic system and is, therefore, dependent upon TP or ψ_p as well as nature of wall.	3. It is dependent upon OP or ψ_s of the system, OP or ψ_s of outside solution and the resistance that system puts against entry of more solvent into it.
4. OP or Ψ_s changes slightly in an osmotic system.	4. It is variable and changes from zero to equal the OP.	4. It is commonly equal and opposite to TP or ψ_p.	4. It varies from zero to equal the OP or ψ_s.

5. It helps in retaining water inside cells.	5. It provides turgidity to the cells, tissues and softer organs.	5. Wall pressure prevents bursting of cells and limits expansion.	5. It controls entry of water into cells and water relations amongst cells.
6. OP or ψs causes movement of water across a semipermeable membrane.	6. Development of turgor pressure or pressure potential is essential for growth of cells.	6. Reduction of wall pressure is required for growth of cells.	6. DPD or ψ_w determines whether a cell will lose or gain water from an external solution or adjacent cells.

PLASMOLYSIS

Shrinkage of the protoplast of a cell from its cell wall under the influence of a hypertonic solution is called plasmolysis. Hypertonic solution causes **exosmosis** or withdrawal of water from cytoplasm and then the central vacuole of cell. The size of cytoplasm as well as central vacuole and hence protoplast becomes reduced. The pressure on the wall is simultaneously reduced and the elastic wall contracts causing a reduction in cell size. This is first stage of plasmolysis called **limiting plasmolysis.** At limiting plasmolysis, the pressure potential (ψ_p) is zero and the osmotic concentration of cell interior is just equivalent to that of external solution (isotonic). The cell is called **flaccid.**

The extra hypertonic external solution continues to withdraw water from the central vacuole by exosmosis. Central vacuole shrinks further causing a similar shrinkage of protoplast from the cell wall. Pressure potential becomes negative. Initially the protoplast withdraws itself from the corners. This stage is known as **incipient plasmolysis**. The hypertonic solution now enters the cell in between the protoplast and the cell wall. Due to continued exosmosis, protoplast shrinks further and withdraws from the cell wall except one or a few points. It is known as **evident plasmolysis.**

Deplasmolysis

The swelling up of a plasmolysed protoplast under the influence of hypotonic solution or water is called deplasmolysis. It is due to **endosmosis**. Deplasmolysis is possible only immediately after plasmolysis otherwise the cell protoplast becomes permanently damaged. During deplasmolysis water diffuses into protoplast. It enters the central vacuole and cytoplasm. Consequently, the protoplast swells up. It first comes in contact with cell wall and then starts building a pressure on cell wall. This pressure is called turgor pressure. It makes the cell turgid.

Differences between Plasmolysis and Deplasmolysis

Plasmolysis	*Deplasmolysis*
1. It occurs when a tissue is placed in hypertonic solution.	1. Deplasmolysis occurs when freshly plasmolysed cells are kept in hypotonic solution or pure solvent.
2. Plasmolysis involves shrinkage of protoplast from the cell wall.	2. It is swelling of shrunken protoplast so as to come in contact with cell wall.
3. Plasmolysis is a result of exosmosis.	3. Deplasmolysis is a result of endosmosis.
4. Prolonged plasmolysis is not reversible.	4. Deplasmolysis is reversible even after an interval.

Expt. 4. Experiment to show Plasmolysis

Apparatus. A fresh filament of *Spirogyra* or a fresh peel from the lower leaf surface of *Rhoeo spathacea*

(= *R. discolor* = *Tradescantia discolor*), 10% solution of potassium nitrate or common salt, a slide, cover slip, microscope, water, dropper and a piece of blotting paper.

Working. Mount a fresh filament of *Spirogyra* or peel of lower leaf surface of *Rheo spathacea* (= *R. discolor*) on a slide in a drop of water. Examine it under microscope and note that the cells are fully distended or turgid. Now replace the drop of water with a drop of 10% solution of potassium nitrate or common salt. The cells shrink in size. The shrinking protoplast becomes conspicuous due to presence of ribbon-shaped chloroplasts in *Spirogyra* and coloured sap in *Rhoeo*. It is followed by the separation of the protoplast from the cell wall due to its contraction. This shrinkage of the protoplast from the cell wall under the influence of a strong solution is called plasmolysis (Figs. 11.16 – 17).

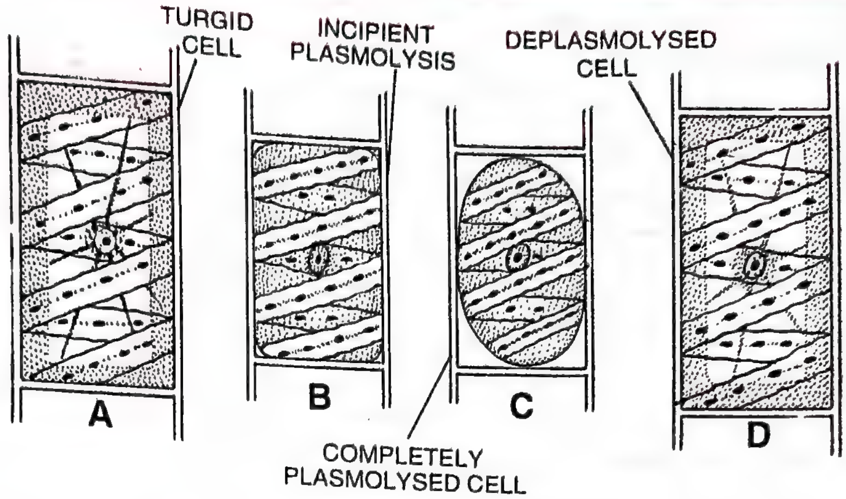


Fig. 11.16. Plasmolysis in *Spirogyra* cells. A, turgid cell; B, incipiently plasmolysed cell; C, plasmolysed cell; D, deplasmolysed cell.

If potassium nitrate or common salt solution is now replaced by water again, the protoplast starts swelling. It comes in contact with the cell wall and the cell regains its original size. The swelling up of the plasmolysed protoplast under the influence of a weak solution or water is called **deplasmolysis** (Fig. 11.16D).

Results. (i) The shrinkage of the protoplast under the influence of 10% potassium nitrate or common salt solution and later its swelling when placed in water shows that the protoplast possesses an osmotically active solution in its interior. The solution is called **cell sap**. (ii) The cell wall is fully permeable. (iii) The contraction of the cell as a whole is due to the reduction in the turgor pressure till the wall pressure becomes zero. When the wall pressure becomes zero, the cell does not contract further. Only the protoplast shrinks now. (iv) Shrinkage of protoplast during plasmolysis and its expansion during deplasmolysis points out that the cytoplasm lying around the central vacuole acts as a semi-permeable membrane. (v) 10% potassium nitrate or common salt solution is stronger than cell sap.

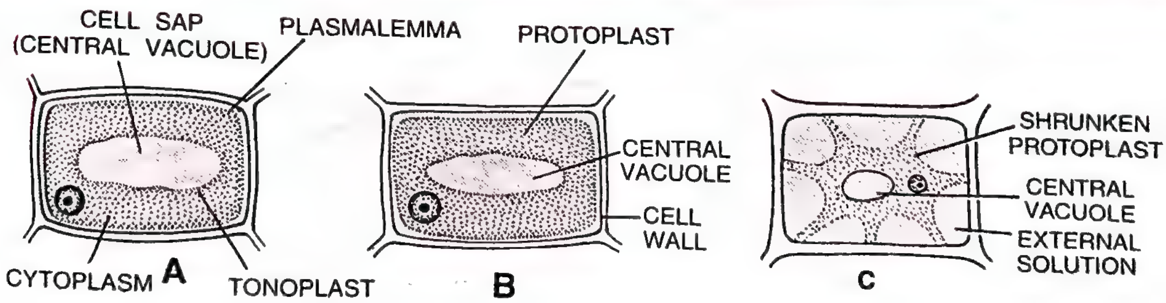


Fig. 11.17. Plasmolysis in a cell. A, turgid cell; B, incipient plasmolysis; C, evident plasmolysis.

Precautions. (i) The experimental material (*Spirogyra* filament, *Rhoeo* leaf peel) must be fresh and living. (ii) The external solution must not be too strong as to become toxic. (iii) Wash at least once the experimental material with external solution so that chances of dilution are minimised. (iv) For deplasmolysis, the material has to be washed at least twice with water.

Importance of Plasmolysis

1. Plasmolysis proves that the cell membrane is semipermeable.
2. It shows that the cell wall is elastic as well as permeable.

3. Osmotic pressure of a cell can be measured by plasmolysis. It will be roughly equivalent to the osmotic pressure of a solution which will be strong enough to cause only incipient plasmolysis.

4. Plasmolysis can be shown only by living cells. It can, therefore, determine whether a cell is living or dead.

5. By salting tennis lawns, the weeds can be killed due to permanent plasmolysis and consequent death of their cells.

6. Plants are not allowed to grow in the cracks of the walls by the method of salting.

7. Salting of pickles, meat and fish and sweetening of the jams and jellies with sugar, kill the spores of fungi and bacteria.

8. Excessive concentration of chemical fertilizers at one place in the soil should be avoided, otherwise the plants will die down.

Dead cells are fully permeable. It can be observed by cutting beet root into thin slices and washing them thoroughly under tap water till no more colour diffuses out. The slices are placed in water. No coloured sap comes out of them. Heat them. A reddish sap begins to come out of the slices. Heating has killed the cell membranes and made them permeable so that the sap diffuses out.

WATER ABSORPTION

SOIL WATER

Soil is the upper weathered, humus, mineral water and air containing layer of the earth's crust which supports plant life. Water is an important constituent of soil because all land plants depend upon it for their requirement of water. Deep in the soil and above the impermeable stratum, water occurs freely in the pervious rocky matter. It is called **ground water.** Ground water bearing pervious stratum is known as **aquifer**. The upper layer of ground water is called **water table**. In the region of water table soil is completely saturated with water. Air is excluded. Tubewells and hand pumps bring ground water to the surface. Very few plants can send their roots upto fringe of the water table due to deficiency of air. The plants which do so, are called **phreatophytes**, *e.g.*, *Populus deltoides*, *Alhagi pseudalhagi*, *Tamarix*, *Prosopis cineraria* etc. Phreatophytes have been used successfully to locate under-ground water since the period of Varahmihira (Brihat Samhita, 5th century A.D.).

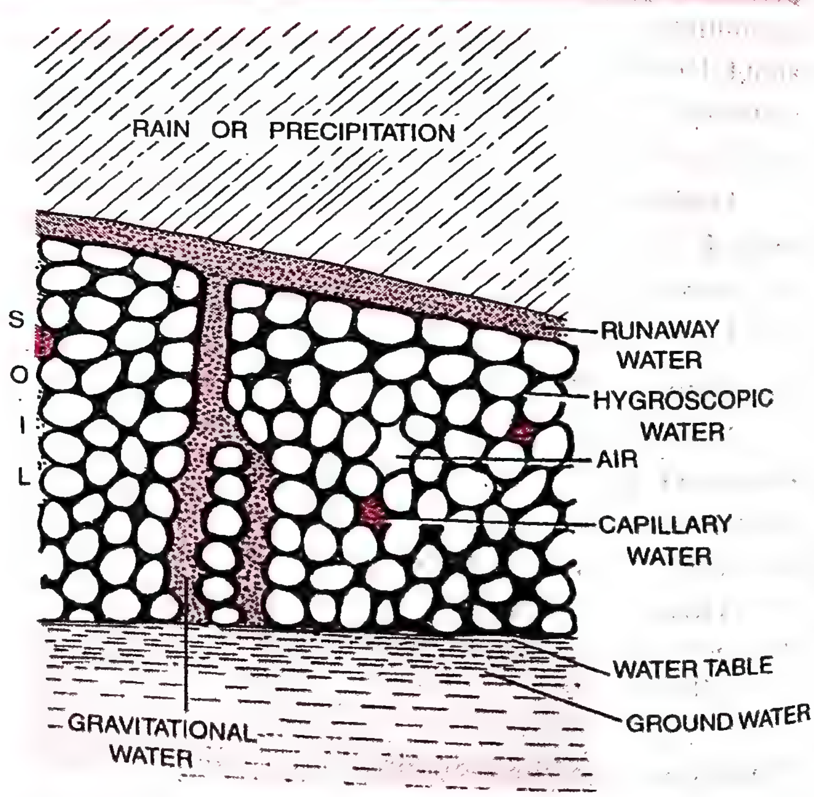


Fig. 11.18. Fate of water falling on soil in the form of rain.

Soil water, important to most plants, is the one present in 1–2m of soil because their roots are generally restricted to this region. Water

is present in the soil in five forms— capillary water, gravitational water, hygroscopic water, combined water and water vapours. The ultimate source of all soil water is rain or irrigation. A part of rain water does not enter the soil but is drained away from soil-surface along the slope. It is called **run-away water** or **run-off** (Fig. 11.18).

Capillary Water. It is the water present in soil narrow spaces or **micropores** of soil having a diameter of 20 µm or below. The amount of capillary water which can be present in a soil depends upon the abundance of micropores. Capillary water is held in the soil by capillary forces. It, therefore, does not fall down to water table by gravity. Only capillary water is available to plant roots for absorption. However, roots are unable to absorb water from capillaries below the diameter of 0.2 µm.

Excess rain or irrigation is not useful to plants. Rather it can be harmful because excess of water would expel soil air. This happens when flow of gravitational water is prevented and soil is covered with water for longer periods. The optimum or maximum amount of water retained per unit dry weight of soil after the stoppage of gravitational flow is called **field capacity**. It is 25–35% in common loam soils. Soil moisture beyond field capacity produces **water logging.** If soil water is not replenished from time to time, a stage is reached when the plants growing in it become permanently wilted and die. It is known as **permanent wilting percentage** (PWP) or **permanent wilting coefficient** (PWC). At permanent wilting percentage the soil contains about 10% of water which is either present in extremely fine micropores or in the non-available stage.

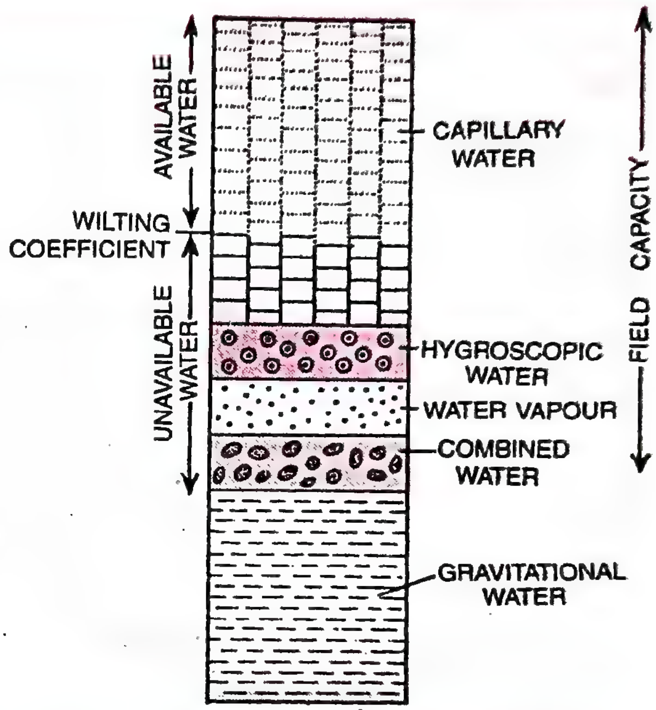


Fig. 11.19. Various fractions of soil water.

Available Water (Fig. 11.19). The total water content present in the soil is called **holard**. The water available to plants is **chresard** (= growth water = **available water**). It consists of roughly 75% of capillary water. The rest of soil water (hygroscopic, combined, water vapour and 25% of capillary water) is called **echard** or unavailable water.

Movement of Substances (Long Distance Transport)

Substances move through the plant by means of **diffusion, facilitated diffusion, active transport** and **mass** or **bulk flow**. Gases move into and out of the plant entirely through diffusion. Movement of water into and out of cells occurs by a special type of diffusion called osmosis. Ions move into cells through diffusion, facilitated diffusion and active transport. However, these methods cannot provide a mechanism for translocation or long distance transport. For example, movement of a molecule through diffusion across a cell of 50 µm size will require 2.5 seconds. 1 metre transport through diffusion will approximately take 32 years. To overcome this deficiency, plants have developed a **mass** or **bulk flow system** which operates through development of pressure difference between the source and sink. In mass or bulk flow all the susbtances dissolved or suspended in solution travel at the same pace, just as silt suspended in the flowing river. It is quite different from diffusion where substances move independently according to their concentration gradients.

Long distance bulk movement of substances that occurs through conducting or vascular tissues of plants is called translocation. There are two vascular tissues, xylem and phloem. Xylem **translocation** is mainly from roots to aerial parts. It passes water with mineral salts, some organic nitrogen and hormones. Phloem translocates organic substances and inorganic solutes first from leaves to all other parts of the plant and storage organs. Storage organs re-export organic nutrients to those parts which require the same as newly formed leaves and fruits. Translocation operates either due to positive hydrostatic pressure gradient (like a garden hose) as in phloem or a negative hydrostatic pressure gradient (like suction through a straw) as in xylem.

Table 11.2. Movement of Substances through the Plant

	Uptake	Transport	Elimination
Water	osmosis into root	mass flow through xylem	diffusion (transpiration) through stomata (also small loss from cuticle and lenticels)
Solutes	diffusion or active transport into root	mass flow through xylem (mainly inorganic solutes) or phloem (mainly organic solutes)	shedding of leaves, bark, fruits and seeds; otherwise retained until death or passed to next generation in embryo of seed
Gases	diffusion through stomata, lenticels,	diffusion through intercellular spaces	diffusion through stomata, lenticels, epidermis

WATER ABSORBING SYSTEM

Plants have the potentiality to absorb water through their entire surface right from root, stem, leaves, flowers, etc. However, as water is available mostly in the soil, only the underground root system is specialized to absorb water. Roots are often extensive and grow rapidly in the soil. Ditmer (1937) has found the total length of the root system of a 4-month old Rye plant (*Secale cereale*) to be 620 km with a daily increase of 5 km. The surface area was calculated to be 255 square metres. Root ends of Maize grow by 6% of their volume every ten minutes (Hsiao, 1973). Such a spreading and growing root system allows the plant to absorb water efficiently from a restricted area in which it occurs.

In roots, the most efficient region of water absorption is the root hair zone. Each root hair zone has thousands of root hairs. Ditmer has estimated that a four month old Rye plant bears as many as 14 billion root hairs, with a length of over 10,000 km and total surface area of over 400 square metres. Root hairs are specialized for water absorption. They are tubular outgrowths of 50–1500 μm (0.05–1.5 mm) length and 10 μm in breadth. Each root hair has a central vacuole filled with osmotically active cell sap and a peripheral cytoplasm. The wall is thin and permeable with pectic substances in the outer layer and cellulose on the inner layer. Root hairs pass into capillary micropores, get cemented to soil particles by pectic compounds and absorb capillary water.

Pathways of Water Movements in Roots

There are two pathways of water passage from root hairs to xylem inside the root, apoplast and symplast (Figs. 11.20–21). (i) **Apoplast Pathway.** Here water passes from root

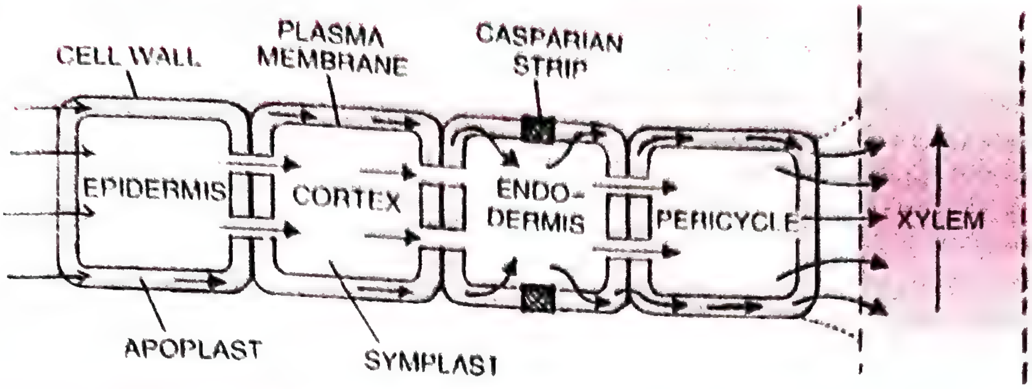


Fig. 11.20. Pathways of water movement inside the root.

hair to xylem through the walls of intervening cells without crossing any membrane or cytoplasm. The pathway provides the least resistance to movement of water. However, it is interrupted by the presence of impermeable lignosuberin **casparian strips** in the walls of endodermal cells. (ii) **Symplast Pathway.** Water passes from cell to cell through their protoplasm. It does not enter cell vacuoles. The cytoplasm of the adjacent cells are connected through bridges called **plasmodesmata**. For entering into symplast, water has to pass through plasmalemma (cell membrane) atleast at one place. It is also called **transmembrane pathway**. Symplastic movement is aided by **cytoplasmic streaming** of individual cells. It is, however, slower than apoplastic movements.

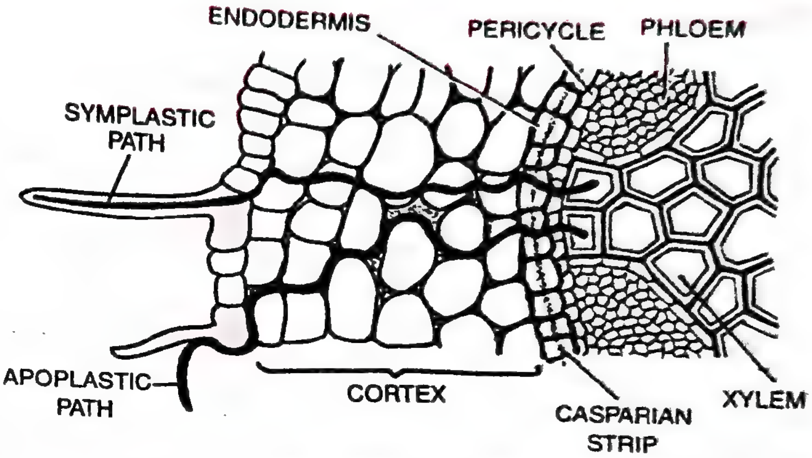


Fig. 11.21. Apoplastic and symplastic pathways of water and ions transport across the root.

Both the pathways are involved in the movement across the root. Water flows via apoplast in the cortex. It enters the symplast pathway in the endodermis where walls are impervious to flow of water due to the presence of casparian strips. Here, only plasmodesmata are helpful to allow passage of water into pericycle from where it enters the xylem. Mineral nutrients also have the same pathway as that of water. However, their absorption and passage into symplast mostly occurs through active absorption. Once inside the xylem, the movement is purely along the pressure gradient.

Mycorrhizal Water Absorption. In mycorrhiza a large number of fungal hyphae are associated with the young roots. The fungal hyphae extend to sufficient distance into the soil. They have a large surface area. The hyphae are specialised to absorb both water and minerals. The two are handed over to the root which provides the fungus with both sugars and N-containing compounds. Mycorrhizal association between fungus and root is often obligate. *Pinus* and orchid seeds do not germinate and establish themselves into plants without mycorrhizal association.

Differences between Apoplast and Symplast Pathways of Water Movement	
Apoplast Pathway	*Symplast Pathway*
1. It consists of nonliving parts of plant body, *i.e.*, cell walls and intercellular spaces.	1. It consists of living parts of plant body, *i.e.*, protoplasts connected by plasmodesmata.
2. There is little resistance in the movement of water.	2. Some resistance occurs in the movement of water through symplast.
3. It is faster.	3. It is slightly slower.
4. Metabolic state of root does not affect apoplast pathway.	4. Metabolic state of root directly affects symplast pathway.

MECHANISM OF WATER ABSORPTION

Water absorption is of two types, passive and active (Renner, 1912, 1915).

Passive Water Absorption

The force for this type of water absorption originates in the aerial parts of the plant due to loss of water in transpiration. This creates a tension or low water potential of several atmospheres in the xylem channels. Creation of tension in the xylem channels of the plant is evident from (i) A negative pressure is commonly found in the xylem sap. It is because of it that water does not spill out if a cut is given to a shoot. (ii) Water can be absorbed by a shoot even in the absence of the root system. (iii) The rate of water absorption is approximately equal to the rate of transpiration. Root hairs function as tiny osmotic systems. Each root hair has a thin permeable cell wall, a semi-permeable cytoplasm and an osmotically active cell sap present in the central vacuole. Because of the latter a root hair cell has a water potential of –3 to –8 bars. Water potential of the soil water is –.1 to –.3 bars. As a result water of the soil passes into the root hair cell. However, water does not pass into its vacuole. Instead it passes into apoplast and symplast of cortical, endodermal and pericycle cells and enter the xylem channels passively because of the very low water potential due to tension under which water is present in them, caused by transpiration in the aerial parts. A gradient of water potential exists between root hair cell, cortical cell, endodermal, pericycle and xylem channels so that flow of water is not interrupted.

Active Water Absorption

It is the absorption of water due to forces present in the root. Living cells in active metabolic condition are essential for this. Auxins are known to enhance water absorption (even from hypertonic solution) while respiratory inhibitors reduce the same. Therefore, energy (from respiration) is involved in active water absorption. Water absorption from soil and its inward movement may occur due to osmosis. Passage of water from living cells to the xylem channels can occur by : (i) Accumulation of sugars or salts in the tracheary elements of xylem due to either secretion by the nearby living cells or left there during decay of their protoplasts. (ii) Development of **bioelectric potential** favourable for movement of water into xylary channels. (iii) Active pumping of water by the surrounding living cells into tracheary elements.

Root pressure is a manifestation of active water absorption.

Differences between Active and Passive Water Absorption	
Active Water Absorption	*Passive Water Absorption*
1. It cannot occur in the absence of roots.	1. Passive water absorption can occur even in the absence of roots.
2. Root cells play an active role in this type of water absorption.	2. Root cells have no active role in this type of water absorption.
3. Living root cells either pump water into xylem or deposit solutes in the same.	3. Transpiration creates a tension in xylem.
4. Force for active water absorption lies in the roots.	4. Force for this type of water absorption develops in the shoot.
5. It is found in certain seasons only.	5. It is found throughout the year.
6. Active water absorption is reported in some plants only.	6. Passive water absorption occurs in all plants.
7. It uses metabolic energy.	7. It uses radiation energy.
8. Active water absorption is immediately influenced by metabolic poisons.	8. Metabolic poisons do not have any immediate effect on passive water absorption.
9. It is not influenced by transpiration.	9. It is dependent upon transpiration.
10. It creates a positive pressure in the xylem channels.	10. Passive water absorption produces a negative pressure in xylem channels.
11. It is manifested in the form of root pressure.	11. It is manifested in the form of transpiration pull.

ASCENT OF SAP

(Translocation of Water)

Sap is water with dissolved ingredients (minerals). The upward movement of water from roots towards the tips of stem branches and their leaves is called ascent of sap. It occurs through the tracheary elements of xylem. That the ascent of sap occurs through xylem can be demonstrated by the following experiment.

Experiment 5. Stain Test

Apparatus. A leafy shoot (*e.g.*, Balsam) preferably with white flowers freshly cut under water, 2% eosine solution, a stand, razor, slide and microscope.

Working. Take a leafy shoot freshly cut under water. Dip the cut end of the shoot in an eosine solution contained in a beaker. Hold the leafy shoot erect by means of a stand.

After some time veins of the leaves will become red (Fig. 11.22 A). Flowers develop the same colour. Even stem may look reddish. Cut thin transverse sections of the stem and leaves. Observe them under the microscope. The walls of tracheids and vessels will be found coloured (Fig. 11.22 B).

Results. The veins of the leaf consist of vascular bundles. The

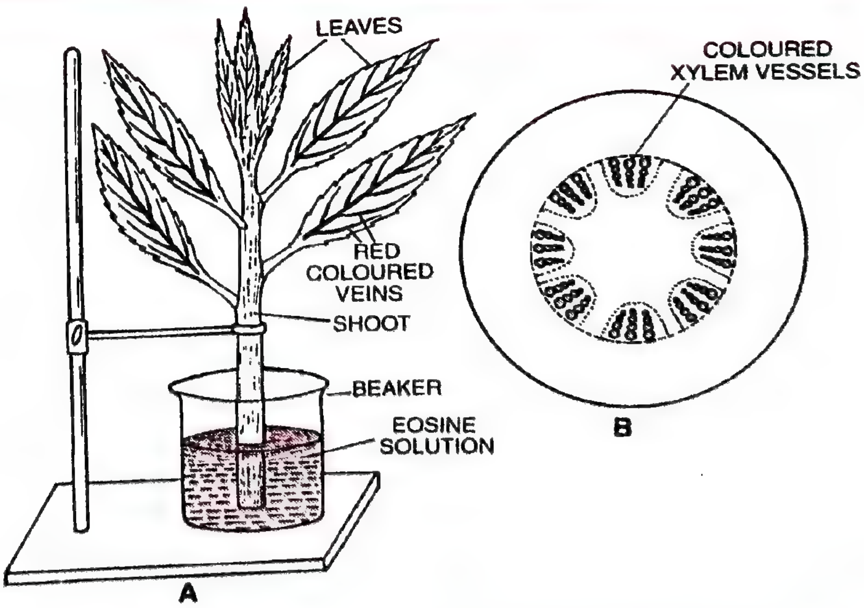


Fig. 11.22. Eosine test to demonstrate ascent of sap.

appearance of red colour in the vein of leaf shows that the coloured water travels through the vascular bundles. The microscopic examination of the sections proves that the coloured water moves through vessels and tracheids of xylem.

Expt. 6. Ringing Experiment (Fig. 11.23)

Apparatus. Two leafy shoots cut under water, a fine knife, a needle, two beakers, stand, water.

Working. Cut two leafy shoots under water. Keep their lower ends dipping in water. In one shoot remove 2–4 cm long ring of bark roughly in the middle region of the shoot. Remove the pith of the stem of this or basal 4–6 cm long region by means of a needle. Remove the xylem in the middle of the second shoot. Fix the shoots to stand and allow the apparatus as such for 1–2 days. The leaves of the first shoot will remain turgid while those of the second shoot would get wilted.

Results. In the first shoot the leaves remain turgid even after 24 hours showing clearly that water continues to rise upwards the leafy shoot despite removal of bark and pith. Removal of bark breaks the continuity of epidermis, cortex, and phloem. As pith has also been discontinued, it shows clearly that epidermis, cortex, phloem and pith do not take part in transport of sap or water. The only tissue left intact is xylem. Xylem, therefore, must be the tissue taking part in the transport of water. This is confirmed from the wilting of the second shoot in which xylem has been discontinued.

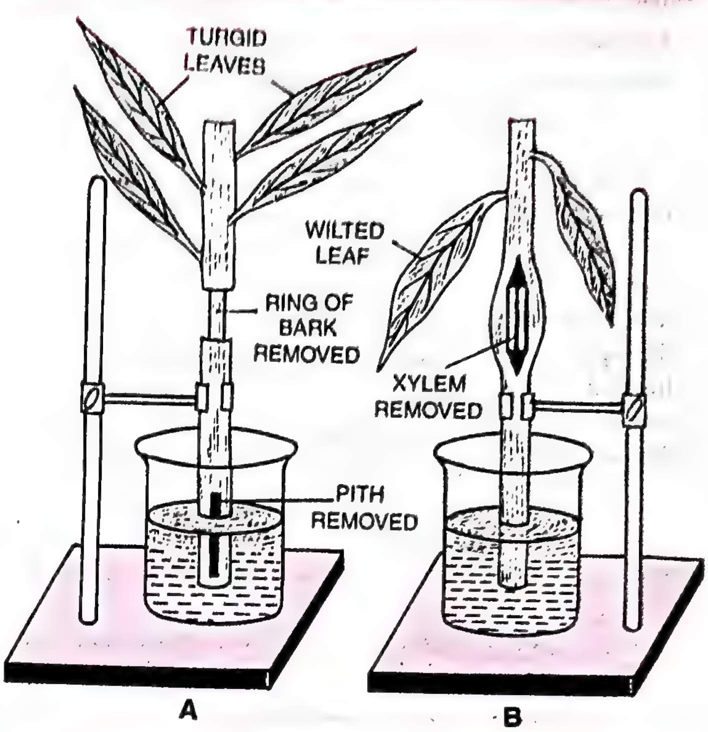


Fig. 11.23. Determination of path of ascent of sap. A, shoot with bark and pith removed remains turgid. B, shoot with xylem removed shows wilting of leaves.

Theories of Ascent of Sap. Water or sap is lifted from near the root tip to the shoot tip against the force of gravity, sometimes to height of 100 metres. The rate of translocation is 25–75 cm/minute (15–45 m/hr). Several theories have been put forward to explain the mechanism of ascent of sap. The three main theories are vital force, root pressure and cohesion tension.

1. **Vital Force Theory**. A common vital force theory about the ascent of sap was put forward by J.C. Bose (1923). It is called **pulsation theory**. The theory believes that the innermost cortical cells of the root absorb water from the outer side and pump the same into xylem channels. However, living cells do not seem to be involved in the ascent of sap as water continues to rise upward in the plant in which roots have been cut or the living cells of the stem are killed by poison and heat (Boucherie, 1840; Strasburger, 1891).

2. **Root Pressure Theory**. The theory was put forward by Priestley (1916). Root pressure is a positive pressure that develops in the xylem sap of the root of some plants. It is a manifestation of active water absorption. Root pressure is observed in certain seasons which favour optimum metabolic activity and reduce transpiration. It is maximum during rainy season in the tropical countries and during spring in temperate habitats. The amount of root pressure commonly met in plants is 1–2 bars or atmospheres. Higher values (*e.g.*, 5–10 atm) are also observed occasionally. Root pressure is retarded or becomes absent under conditions of starvation, low temperature, drought and reduced availability of oxygen. There are three view points about the mechanism of root pressure development: (a) **Osmotic**. Tracheary elements of xylem accumulate salts and sugars. High solute concentration causes

withdrawal of water from the surrounding cells as well as from the normal pathway of water absorption. As a result a positive pressure develops in the sap of xylem. (ii) **Electro-osmotic.** A bioelectric potential exists between the xylem channels and surrounding cells which favour the passage of water into them. (iii) **Nonosmotic.** Differentiating xylem elements produce hormones that function as metabolic sinks and cause movement of water towards them. The living cells surrounding xylem can actively pump water into them.

Experiment 7. Demonstration of Root Pressure (Figs. 11.24–25)

Apparatus. A well watered potted plant of Balsam, Tomato or *Bryophyllum*, a knife, rubber tubing, a narrow glass tubing, coloured water, a stand, manometer, petridish (nondrying oil).

Working. Take a potted plant of Balsam, Tomato or *Bryophyllum* that has been well watered the previous day. Cut off its stem 5–8 cm above the soil level. Fix a narrow glass tubing containing some coloured water to the cut end of stump with the help of rubber tubing. Support the glass tubing by means of a stand. Cover the open end of glass tubing with a small petridish in order to prevent evaporation of water (Fig. 11.24). Instead a drop of nondrying oil can be poured over the surface of coloured water. Mark the level of coloured water as A. Instead of glass tubing, a pressure measuring instrument called **manometer** can also be fixed to the cut end of the stump by means of rubber tubing (Fig. 11.25).

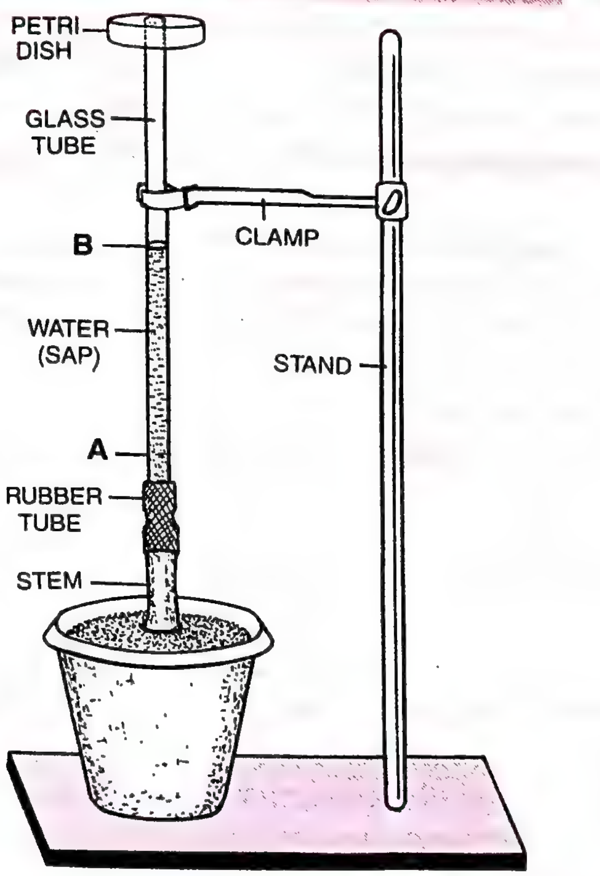


Fig. 11.24. Experiment to demonstrate root pressure.

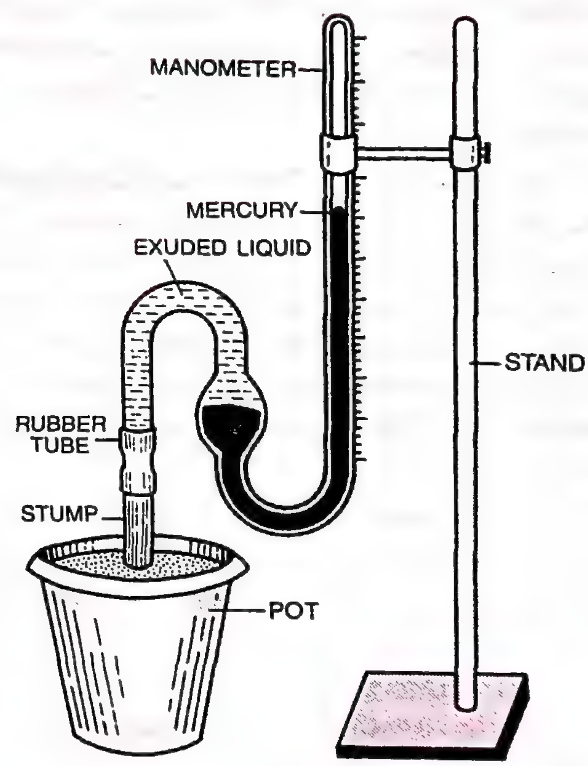


Fig. 11.25. Demonstration of root pressure.

Place the apparatus in a moist, cool and shady place for a couple of hours. The level of coloured water in the glass tubing will rise to the new mark, say B. In case the manometer is attached, the mercury level is found to be pushed upwards. The pressure is read on the graduated scale.

Results. The rise in the level of coloured water in the glass tubing is due to pumping of sap by root. The phenomenon is called **root pressure**. The same is read directly by manometer. A pressure of upto 5 atm. has been recorded by this method.

Precautions. (i) The plant should be well watered but the soil should not be flooded. (ii) The soil should not be deficient in minerals. (iii) Place the apparatus in cool and humid environment. (iv) Evaporation from the open end of the tube be prevented by using nondrying oil or petridish. (v) The plant should be vigorously growing.

Objections to Root Pressure Theory. (i) Root pressure has not been found in all plants. No or little root pressure has been seen in gymnosperms which have some of the tallest trees of the world. (ii) Root pressure is seen only during the most favourable periods of growth like spring or rainy season. At this time the xylem sap is strongly hypertonic to soil solution and transpiration rate is low. In summer when the water requirements are high, the root pressure is generally absent. (iii) The normally observed root pressure is generally low which is unable to raise the sap to the top of trees. (iv) Water continues to rise upwards even in the absence of roots. (v) The rapidly transpiring plants do not show any root pressure. Instead a negative pressure is observed in most of the plants. (vi) The amount of exudation due to root pressure is quite low as compared to the rate of passage through the xylem. (vii) Absorption in detopped plants is quite low as compared to intact plants. (viii) Root pressure disappears in unfavourable environmental conditions while ascent of sap continues uninterrupted. (ix) Root pressure is generally observed at night when evapotranspiration is low. It may be helpful in re-establishing continuous water chains in xylem which often break under enormous tension created by transpiration.

3. **Theory of Capillarity** (Bohm, 1863). Water rises in tubes of small diameter, kept in vessel having water, due to force of surface tension or adhesion and cohesion. Water similarly rises up in the walls of xylem channels due to adhesion. Cohesive force present amongst water molecules pulls the water upwards through the xylem channels. The upward movement will continue till the forces of adhesion and cohesion are balanced by the downward pull of gravity.

Objections to Theory of Capillarity. (i) The value of capillarity is very small. It can raise water to a height of about 1 metre in vessels of normal diameter (0.03 mm). Therefore, if operational it will be useful to only small sized palnts. (ii) Capillarity occurs only when base of the tube dips in container having water. Xylem vessels are not directly connected with soil water. (iii) Rise due to capillarity will increase when the lumen of vessels is less. Tall plants should, therefore, have narrow vessels as compared to smaller plants. The truth is, however, reverse. (iv) Capillarity cannot operate in plants having tracheids due to the presence of end walls.

4. **Cohesion Tension Theory** (Cohesion–Tension and Transpiration Pull Theory). The theory was put forward by Dixon and Joly in 1894. It was further improved by Dixon in 1914. Therefore, the theory is also named after him as **Dixon's theory of ascent of sap.** Today most of the workers believe in this theory. The main features of the theory are:

(a) *Continuous Water Column.* There is a continuous column of water from root through the stem and into the leaves. The water column is present in tracheary elements. The latter do operate separately but form a continuous system through their unthickened areas. Since there are a large number of tracheary elements running together, the blockage of one or a few of them does not cause any breakage in the continuity of water column (Scholander, 1957). The column of water does not fall down under the impact of gravity because forces of transpiration provide both energy and necessary pull. **Cohesion, adhesion** and **surface tension** keep the water in place.

(b) *Cohesion or Tensile Strength.* Water molecules remain attached to one another by a strong mutual force of attraction called **cohesion force**. The mutual attraction is due to **hydrogen bonds** formed amongst adjacent water molecules (Fig. 11.26). On account of cohesion force, the water column can bear a tension or pull of upto 100 atm (Mac Dougal, 1936). Therefore, the cohesion force is also called **tensile strength**. Its theoretical value is about 15000 atm but the measured value inside the tracheary elements ranges between

45 atm to 207 atm (Dixon and Joly, 1894). Water column does not further break its connection from the tracheary elements (vessels and tracheids) because of another force called **adhesion** force between their walls and water molecules. Water molecules are attracted to one another more than the water molecules in the gaseous state. It produces **surface tension** that accounts for high capillarity through tracheids and vessels.

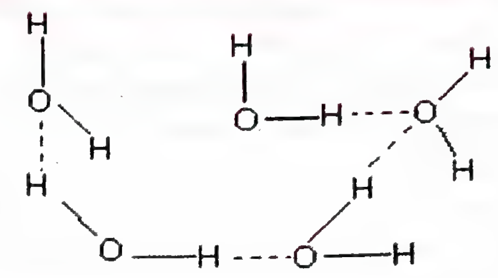


Fig. 11.26. Cohesion force due to hydrogen bonding between water molecules.

(c) *Development of Tension or Transpiration Pull.* Intercellular spaces present amongst mesophyll cells of the leaves are always saturated with water vapours. The latter come from the wet walls of mesophyll cells. The intercellular spaces of mesophyll are connected to the outside air through stomata. Outside air is seldom saturated with water vapours. It has a lower water potential than the moist air present inside the leaf. Therefore, water vapours diffuse out of the leaves. The mesophyll cells continue to lose water to the intercellular spaces. As a result curvature of meniscus holding water increases resulting in increase in surface tension and decrease in water potential, sometimes to –30 bars. The mesophyll cells withdraw water from the deeper cells as its molecules are held together by hydrogen bonds.

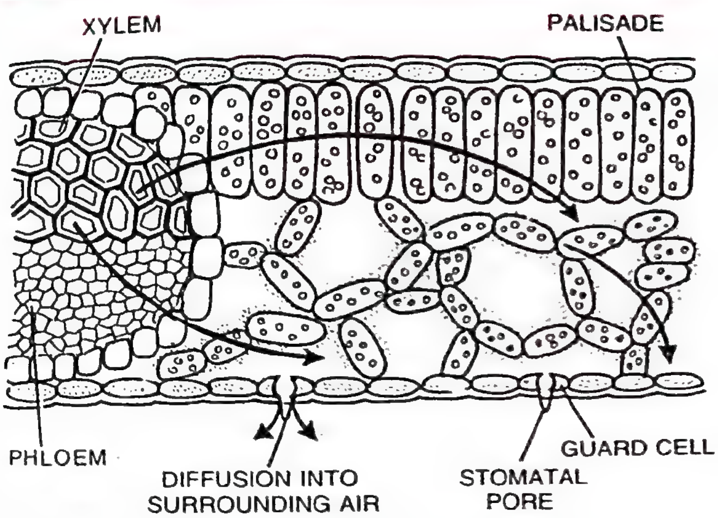


Fig. 11.27. Water movement in leaf and development of pressure gradient between outside air and leaf air spaces, leaf air spaces and mesophyll cells, mesophyll cells and water filled xylem of leaf veins.

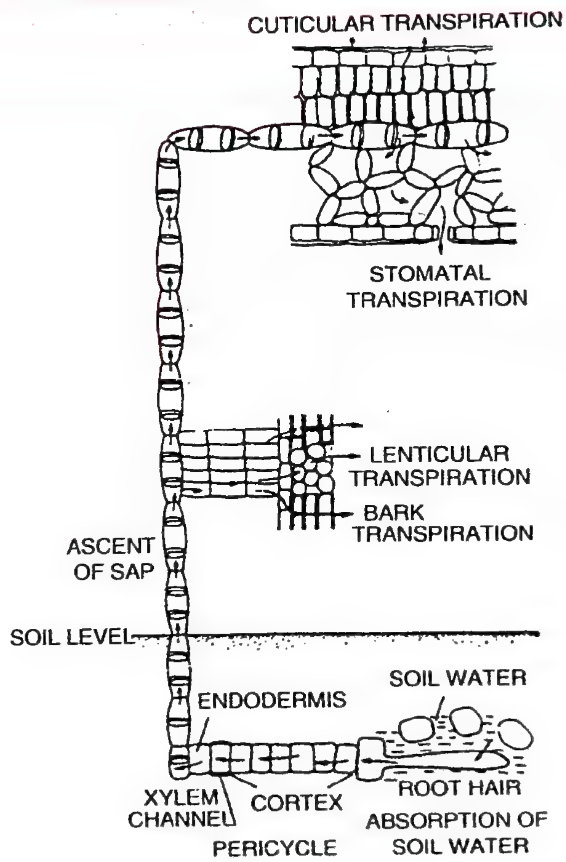


Fig. 11.28. Path of water through the plant.

The deeper cells in turn obtain water from the tracheary elements. The water in the tracheary elements would, therefore, come under **tension**. A similar tension is felt in millions of tracheary elements lying adjacent to the transpiring cells. It causes the whole water column of the plant to come under tension. As the tension develops due to transpiration, it is also called **transpiration pull**. On account of tension created by transpiration, the water column of the plant is pulled up passively from below to the top of the plant like a rope (Fig. 11.28). As a tension of one atmosphere is sufficient to pull

water to a height of about 10 metres, a tension of 10–20 atm is sufficient to raise water to the height of the tallest tree over 130 m. It overcomes, (i) gravitational pull, (ii) resistance of narrow xylem channels and their end walls, (iii) resistance of living cells of the root that lie in the path of water from soil to xylem, (iv) resistance offered by water coming out of narrow capillary pores of the soil.

Evidences. (i) The rate of water absorption and hence ascent of sap closely follows the rate of transpiration. (ii) Evaporation of water from a porous pot or atmometer can produce a tension in the water column present in attached tube. It can even raise a column of mercury to sufficient height (Fig. 11.29). (iii) Shoot attached to a tube having water and dipping in a beaker having mercury can cause the movement of mercury into the tube showing transpiration pull (Fig. 11.30). (iv) In a branch cut from a rapidly transpiring plant, water snaps away from the cut end showing that the water column is under tension. (v) With the help of dendrograph it is found that tree trunks contract during the day time and expand during the night. Contraction is caused by narrowing of tracheary elements when the contained water is under tension. (vi) The maximum tension observed in water column is 10–20 atm. It is sufficient to pull the water to the top of the tallest trees of even more than 130 metres in height. The tension cannot break the continuity of water column as cohesive force of xylem sap is 45 to 207 atm. (vii) Gymnosperms are at a disadvantage in the ascent of sap because of the presence of tracheids instead of vessels in angiosperms. However, tracheidal xylem is less prone to gravitation under tension. Therefore, most of the tall trees of the world are redwoods and conifers.

Objections. (i) The gases dissolved in sap shall form air bubbles under tension and high temperature. Air bubbles would break the continuity of water column and stop ascent of sap due to transpiration pull. (ii) A tension of upto 100 atm has been reported in the xylem sap by Mac Dougal (1936) while the cohesive force of sap can be as low as 45 atm. (iii) Overlapping cuts do not stop ascent of sap though they break the continuity of water column.

Experiment 8. Demonstration of Evaporation Pull.

Apparatus. An unglazed porous pot or atmometer, a cork, a long narrow glass tube, wax or vaseline, mercury, air free water.

Working. Fill an unglazed porous pot and a narrow but strong glass tube of 50–100 cm. length with air free water (boiled and cooled). Make the joints air tight by wax or vaseline. Cover the free end of glass tube with your finger and invert it over the

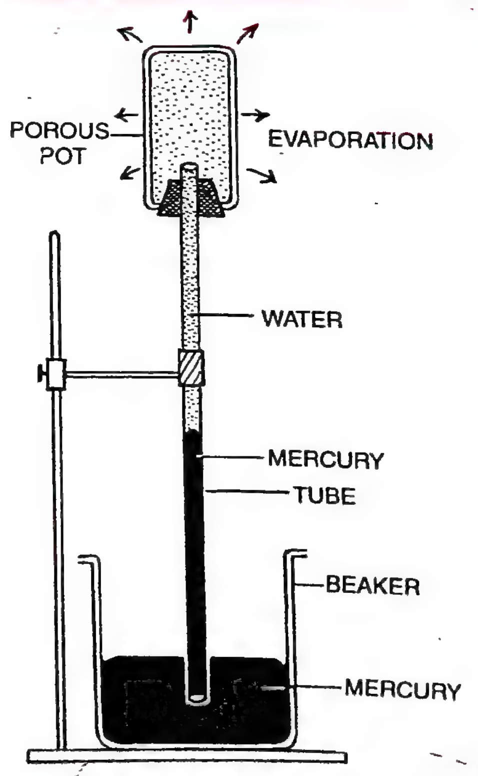


Fig. 11.29. Demonstration of pull due to evaporation.

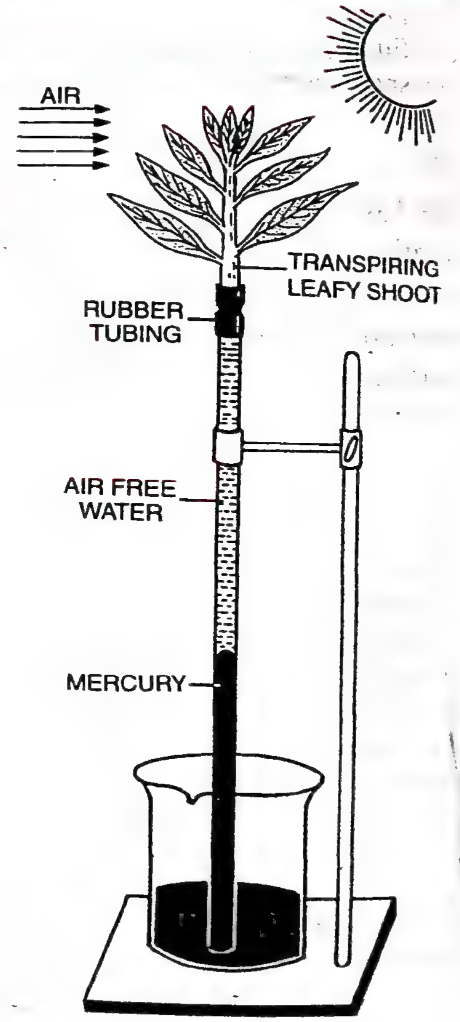


Fig. 11.30. Demonstration of pull due to transpiration.

base of the beaker containing mercury. Clamp the apparatus to a stand in upright position and place it in a dry area, sunlit or below a ceiling fan. Soon the mercury will be seen rising in the tube while the amount of water present in the tube will correspondingly decrease (Fig. 11.29).

Results. Reduction in the amount of air free water in the tube indicates that the same has gone into atmometer which must have lost a part of its water through evaporation. It produces the tension in the water column that results in upward pulling of water as well as mercury (which is 13.6 times heavier than water).

Precautions. (i) The joint between the atmometer and tube should be air tight. (ii) Pores of atmometer must be open to bring about evaporation of water. (iii) Use only air free water otherwise water column can break due to formation of air bubbles. (iv) Remove the finger from the end of tube only when it has thoroughly dipped in mercury.

Experiment 9. Demonstration of Transpiration Pull.

Apparatus. A 50–100 cm long glass tube, rubber tubing, fresh leafy shoot cut under water, air free water, mercury, beaker, stand and rubber solution.

Working. Fill a 50–100 cm long tube with air free water. Close one end of the tube with your finger. Fix a short piece of thick rubber tubing over the other end. Through it insert the cut end of a shoot in the tube. Make the connections air tight with rubber solution. Dip the free end of the tube in a beaker containing mercury. Hold the tube vertical by means of a stand (Fig. 11.30). Place the apparatus in open dry place. Soon the mercury will be seen rising upwards in the tube.

Results. The rise of mercury in the tube clearly shows that water in the tube is being pulled upwards with a great force. Otherwise mercury, which is 13.6 times heavier than water cannot rise upwards. This pull is caused by transpiration or evaporation of water from the shoot. Hence transpiration produces a **pull** or **suction pressure**. The exact value of the pull is calculated by $\pi r^2 h \times 13.6$ where r is radius of the tube, h is the height to which mercury has gone up.

Precautions. (i) The leafy shoot should be cut under water. Its lower end should be kept dipping in water till fitted into the apparatus. (ii) The joint must be completely air tight. (iii) Use air free water. (iv) The leafy shoot should have a large surface aréa with good rate of transpiration.

TRANSPIRATION

The loss of water in the vapour form from the exposed parts of a plant is called transpiration. The loss of water due to transpiration is quite high —2 litres per day in Sunflower, 36–45 litres in Apple and upto 1 tonne per day in Elm tree. Rather 98–99% of the water absorbed by a plant is lost in transpiration. Hardly 0.2% is used in photosynthesis while the remaining is retained in the plant during growth.

Differences between Evaporation and Transpiration

Evaporation	*Transpiration*
1. Water vapours are formed at the free surface of water.	1. Water vapours are formed mostly in internal tissues of the plant.
2. It takes place at the surface of non-living objects.	2. It occurs at the exposed surface of plants.
3. It is a physical process which is controlled by the environmental conditions like relative humidity and air current.	3. It is both a physical and physiological process. Besides being controlled by the environmental conditions, it is influenced by the rate of water absorption, osmotic pressure of cells, thickness of cuticle and number, position and opening of stomata.
4. Evaporation stops when the air is fully saturated.	4. Formation of vapours continues for some time even after the saturation of outside air. This is due to the fact that the temperature of the leaf is slightly higher than the outside air, and therefore, the saturation point of the internal air is slightly higher.

5. It varies directly according to the velocity of wind.	5. The rate of transpiration is slightly lower than evaporation under the influence of wind velocity because it lowers the leaf temperature.
6. Light does not directly influence the rate of evaporation.	6. Light influences transpiration to a great extent. Stomata usually open in the presence of sunlight resulting in full-scale transpiration. They close during darkness, thus lowering the rate of transpiration to a great extent.
7. Evaporation is comparatively faster.	7. It is a comparatively slow process.
8. It is not much influenced by the structure of the evaporating surface.	8. Transpiration is controlled by anatomy of the transpiring organ.
9. It continues as long as water is available on the surface.	9. It is largely dependent upon absorption of water from the soil.
10. CO_2, *p*H and hormones have no effect on evaporation.	10. Transpiration is influenced by *p*H, CO_2 and hormones.

Experiment 10. Demonstration of Transpiration

Apparatus. A well-watered potted plant, vaseline, oil cloth, strong thread or clamping rubber bands, glass slab and a bell jar.

Working. Take a small well watered potted plant. Cover the external surface of pot and its soil with oil cloth. Place the potted plant on a glass slab in a cooler place and invert a **dry bell jar** over it. Seal the edges of the bell jar with vaseline so that no air enters the apparatus from outside (Fig. 11.31). Leave the apparatus undisturbed. Soon the interior of the bell jar becomes misty. Afterwards drops of water will be found on the inner surface of the jar.

Results. The drops of water which appear on the inside of the bell jar cannot come from the outside air, nor from the water present in the soil of the pot because both have been properly sealed. The water vapours can come only from the exposed aerial shoot of the plant. Such a loss of water from the plant is called **transpiration**.

Precautions. (i) Do not place apparatus in a very warm place as the water vapours will not be able to condense. (ii) Keep the apparatus undisturbed. (iii) Use a glass slab or smooth surface as the base for the apparatus. (iv) Seal the edges of bell jar so as to avoid the entry of water vapours from outside. (v) Cover the soil and the exterior of the pot properly with oil cloth.

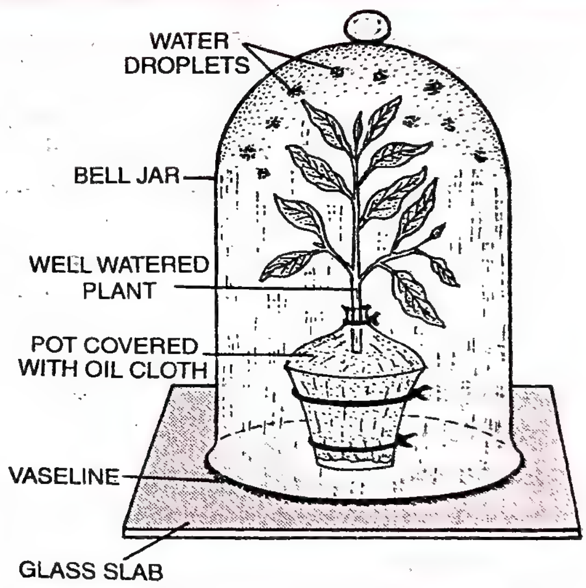


Fig. 11.31. Demonstration of transpiration by bell jar experiment.

Types of Transpiration

Most of the transpiration occurs through foliar surface or surface of the leaves. It is known as **foliar transpiration**. Foliar transpiration accounts for over 90% of the total transpiration. Young stems, flowers, fruits, etc. also transpire a lot. Mature stems transpire very little. Transpiration from stems is called **cauline transpiration**. Depending upon the plant surface transpiration is of the following four types— stomatal, cuticular, lenticular and bark.

1. **Stomatal Transpiration**. It is the most important type of transpiration. Stomatal transpiration constitutes about 50–97% of the total transpiration. It occurs through the **stomata**. The stomata are found mostly on the **leaves**. A few of them occur on the young

stems, flowers and fruits. The stomata expose the wet interior of the plant to the atmosphere. The internal air, therefore, becomes saturated with water vapours. The outside air is seldom saturated with water except just after rains. **Water vapours**, therefore, pass **outwardly** through **stomata** by diffusion. More water evaporates from the internal cells to replace the outgoing water vapours (Fig. 11.32). The stomatal transpiration continues till the stomata are kept open.

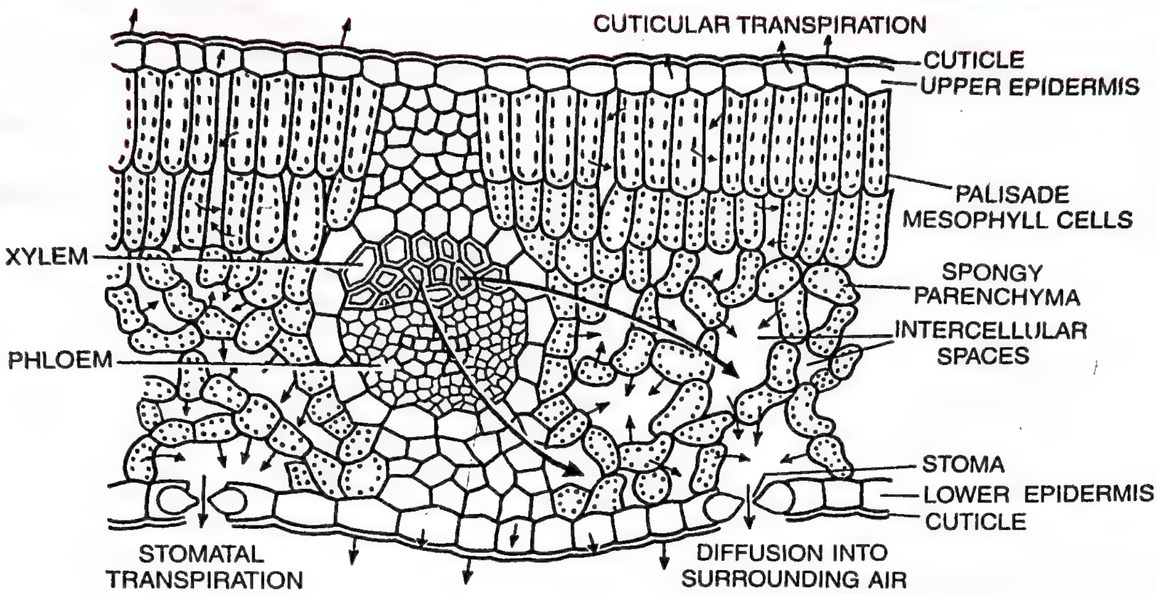


Fig. 11.32. V.S. leaf showing stomatal and cuticular transpiration.

2. **Cuticular Transpiration**. It occurs through the **cuticle** or **epidermal cells** of the **leaves** (Fig. 11.34) and other **exposed parts** of the plant. In common land plants cuticular transpiration is only 3–10% of the total transpiration. In herbaceous shade loving plants where the cuticle is very thin, the cuticular transpiration may be upto 50% of the total. Cuticular transpiration continues throughout day and night.

3. **Lenticular or Lenticellate Transpiration**. It is found only in the **woody branches** of the trees where **lenticels** occur. The lenticular transpiration is only 0.1% of the total transpiration. It, however, continues day and night because lenticels have no mechanism of closure. The **lenticels** connect the **atmospheric air** with the **cortical tissue** of the **stem** through the intercellular spaces present amongst the complementary cells.

4. **Bark Transpiration**. This type of transpiration occurs through corky covering of the stems. Bark transpiration is very little but its measured rate is often more than lenticular transpiration due to larger area. Like cuticular and lenticular types of transpiration, bark transpiration occurs continuously during day and night.

Expt. 11. Demonstration of Transpiration from Foliar Surface

Apparatus. 3–5% cobalt chloride solution, two small pieces of filter paper, desiccator or oven, forceps, leaf clasp, slides, vaseline, a potted plant or fresh shoot of Pipal or Mulberry with one end in water.

Working. Dip two small pieces of filter paper in 3–5% cobalt chloride solution. Take them out and dry in an oven or desiccator till they become **blue**.

Clean the lower surface of leaf gently with dry cotton. Place a dry cobalt chloride paper over it. Quickly cover the paper with a glass slide and seal its sides with vaseline. Fix them to the leaf clasp (Fig. 11.33). Within a few minutes the colour of the cobalt chloride paper will turn **pink**. No such change occurs in the dry cobalt chloride paper kept in between two glass slides with the edges sealed to prevent entry of water vapours from air (Fig. 11.34). Instead of glass slide and vaseline, cellotape can be used in both the cases.

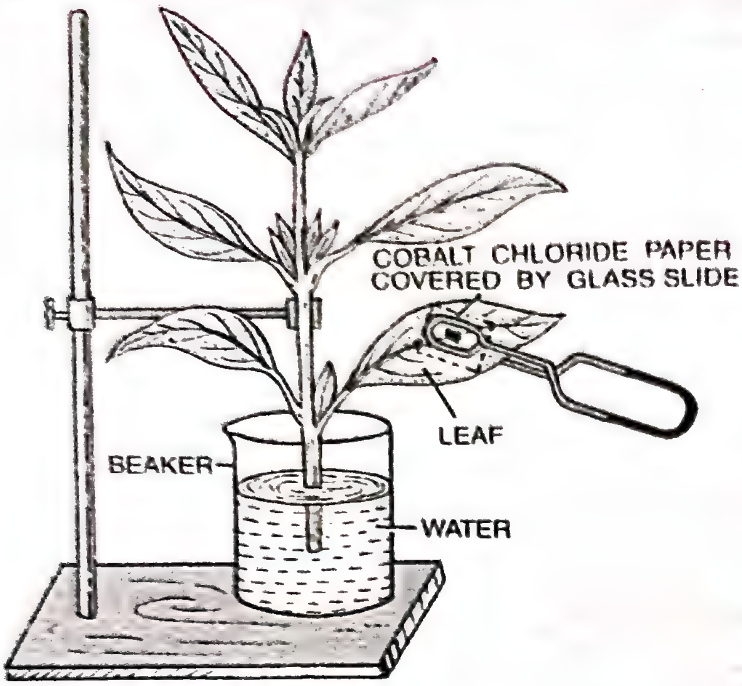


Fig. 11.33. Cobalt chloride paper test to demonstrate transpiration from foliar surface.

Results. Cobalt chloride is blue in the anhydrous condition but becomes pink in contact with water. The change of colour of the cobalt chloride paper from blue to pink clearly indicates that the paper has received water from the surface of leaf.

Precautions. (i) Use dry forceps. (ii) Dry the leaf surface gently with dry cotton. (iii) Handle the leaf gently. (iv) Seal the edges of the slide completely but gently with vaseline.

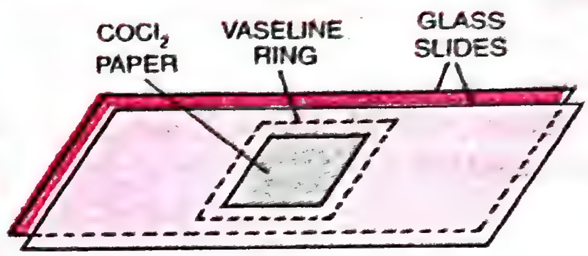


Fig. 11.34. Dry $CoCl_2$ paper remains blue when kept between two glass slides sealed together by vaseline.

Mechanism of Water Loss

In order to form vapours, water present inside the exposed parts of the plant requires a source of heat energy. It is the radiant energy during the day and heat energy from the transpiring organ during the night. In both the cases the temperature of the transpiring organs comes to lie 2–5°C below that of the atmosphere.

The atmosphere is rarely saturated with water vapours. The dry air of the atmosphere has a high DPD (or low water potential)–13.4 atm at 99% relative humidity or RH, 140 atm at 90% RH, 680 atm at 60% and 2055 atm at 20% RH. Such a high DPD or low water potential can overcome various types of resistances water molecules have to meet in changing from liquid phase to vapour phase and the movement of water vapours out of the transpiring organ. The intercellular spaces of the transpiring organ is almost saturated with water vapours. When the stomata are open, the water vapours are drawn from the substomatal cavities to the outside air due to high DPD of the latter. This increases the DPD of the substomatal air which draws more water vapours from the intercellular spaces. The latter in turn get water vapours from the wet walls of mesophyll cells. Stomatal transpiration will continue till the stomata are open. Mechanism of lenticular transpiration is similar to that of stomatal transpiration.

Cuticle is not much permeable to water. However, its molecules absorb water from the epidermal cells by imbibition. The imbibed water is slowly lost to the atmosphere which has a high DPD. Imbibition flow is reduced by the thickness of cuticle. Therefore, a thick cuticle does not allow transpiration to occur through it. Cuticle is shrunken and thicker during the day but at night it expands and becomes loose. Therefore, cuticular transpiration can be more at night. Mechanism of bark transpiration is similar to that of cuticular transpiration.

Stomatal Apparatus (Fig. 11.35)

Stomata (= stomates) are tiny pore complexes found in the epidermis of leaves and other

soft aerial parts. The size is 10–14 μm (range 7–38 μm) in length and 3–12 μm in breadth. The number of stomata per cm^2 of leaf surface varies from 1000–60,000 or 10–600/mm^2. In mesophytic plants, stomata occur both on the upper (adaxial) and lower (abaxial) surfaces. Their number is roughly equal on the two surfaces in grasses and other monocot leaves. In dicot leaves, the number of stomata on the upper surface is usually smaller, even absent in several cases (table 11.3).

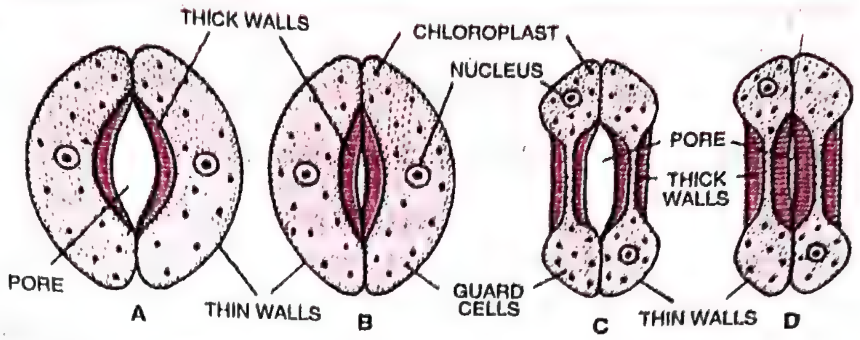


Fig. 11.35. Opened and closed stomata. A, Dicotyledonous. B, Monocotyledonous.

Table 11.3. Stomatal Frequency/mm²

	Upper Surface	*Lower Surface*
Monocots		
Wheat	50	40
Barley	70	85
•Onion	175	175
Maize	52	68
Dicots		
Sunflower	120	175
Alfalfa	169	188
Geranium	20	179
Apple	0	387
Mulberry	0	480

Stomata are meant for the gaseous exchange but are also the main source of transpiration. Each stomate or stoma is surrounded by two small but specialized green epidermal cells called **guard cells**. Because of their small size, they are rapidly influenced by turgor changes. The guard cells contain a few small chloroplasts with peripheral reticulum characteristic of chloroplasts showing C_4 photosynthesis. The guard cells also possess small vacuoles and microbodies. They store starch with the exception of a few. The walls are differentially thickened and elastic. They have folds for expansion (Srivastava and Singh, 1972). **Microfibrils** of these walls are oriented specifically to help in opening and closing of stomata.

In most of the plants the guard cells are **kidney shaped** in outline (Fig. 11.35 A-B). They are joined at their ends. The concavo-convex curvature of two guard cells is variable and causes stomatal pore to open and close. The walls of these guard cells are thickened on inner side. They have one or two pairs of wall extensions or **ledges** to prevent entry of water drops into stomata. The walls are thinner and more elastic on the outer side. When the stomata are to open, these guard cells swell up on the outer side by the development of a high turgor pressure. The inner concave sides also bend out slightly so as to create a pore in between two guard cells. During closure movement, reverse changes occur.

In cereals, members of cyperaceae and some plams the guard cells are **dumb-bell shaped** in outline (Fig. 11.35 C-D). Their expanded ends are thin-walled while middle portions are highly thick-walled. In such cases opening and closing of the stomatal pore is caused by expansion and contraction of thin-walled ends of the guard cells.

Mechanism of Stomatal Movement

Stomata function as **turgor-operated valves** because their opening and closing movement is governed by turgor changes of the guard cells. Whenever, the guard cells swell up due to increased turgor, a pore is created between them. With the loss of turgor the stomatal pores are closed. Stomata generally open during the day and close during the night with a few exceptions. The important factors which govern the stomatal opening are light, high *p*H or reduced CO_2 and availability of water. The opposite factors govern stomatal closure, *viz.*, darkness, low *p*H or high CO_2 and dehydration. There are three main theories about the mechanism of stomatal movements:

1. **Hypothesis of Guard Cell Photosynthesis** (Schwendener, 1881). Guard cells contain chloroplasts. During day the chloroplasts perform photosynthesis and produce sugar. Sugar increases osmotic concentraton of guard cells. It causes absorption of water from nearby epidermal cells. The turgid guard cells bend outwardly and create a pore in between. However, photosynthetic activity of guard cell chloroplasts seems to be negligible.

2. **Classical Starch Hydrolysis Theory** (Fig. 11.36). The main features of the theory were spelled out by Sayre (1923). It was modified by Steward (1964). The guard cells contain starch. At low carbon dioxide concentration (in the morning achieved through photosynthesis by mesophyll and guard cells), *p*H of guard cells rises. It stimulates enzyme phosphorylase. Phosphorylase converts starch into glucose 1-phosphate. The latter is changed to glucose 6-phosphate which undergoes hydrolysis to produce glucose and phosphoric acid.

$$\text{Starch} + nH_3PO_4 \xrightarrow{\text{Phosphorylase}} n\ \text{Glucose 1-phosphate}$$

$$\text{Glucose 1-phosphate} \xrightleftharpoons{\text{Phosphoglucomutase}} \text{Glucose 6-phosphate}$$

$$\text{Glucose 6-phosphate} + \text{water} \xrightarrow{\text{Phosphatase}} \text{Glucose} + H_3PO_4$$

Glucose increases osmotic concentration of guard cells. On account of it, the guard cells absorb water from neighbouring cells, swell up and create a pore in between them. Evening closure of stomata is brought about by increased carbon dioxide content (due to stoppage of photosynthesis) of leaf. It decreases *p*H of guard cells and brings about phosphorylation of glucose. In the presence of phosphorylase, glucose 1-phosphate is changed into starch.

$$\text{Glucose} + \text{ATP} \xrightarrow{\text{Hexokinase}} \text{Glucose 6-phosphate} + \text{ADP}$$

$$\text{Glucose 6-phosphate} \xrightleftharpoons{\text{Phosphoglucomutase}} \text{Glucose 1-phosphate}$$

$$\text{Glucose 1-phosphate} \xrightarrow{\text{Phosphatase}} \text{Starch} + H_3PO_4$$

As a result, osmotic concentration of guard cells falls. They lose water to adjacent epidermal cells. With the loss of turgidity, the guard cells shrink and close the pore in between them.

Objections. (i) Glucose is not found in guard cells at the time of stomatal opening. (ii) Starch $\rightleftharpoons$ Sugar changes are chemically slow while opening and closing of stomata are quite rapid. (iii) Wide changes in *p*H of guard cells cannot be explained on the basis of carbon dioxide concentration. (iv) Onion and some of its relatives do not possess starch or related polysaccharide that can be hydrolysed to the level of glucose. (v) Blue light has been found to be more effective than other wavelengths for opening of stomata. The same cannot be explained by starch hydrolysis theory. (vi) Hydrolysis of starch theory cannot account for high rise in osmotic pressure found in guard cells.

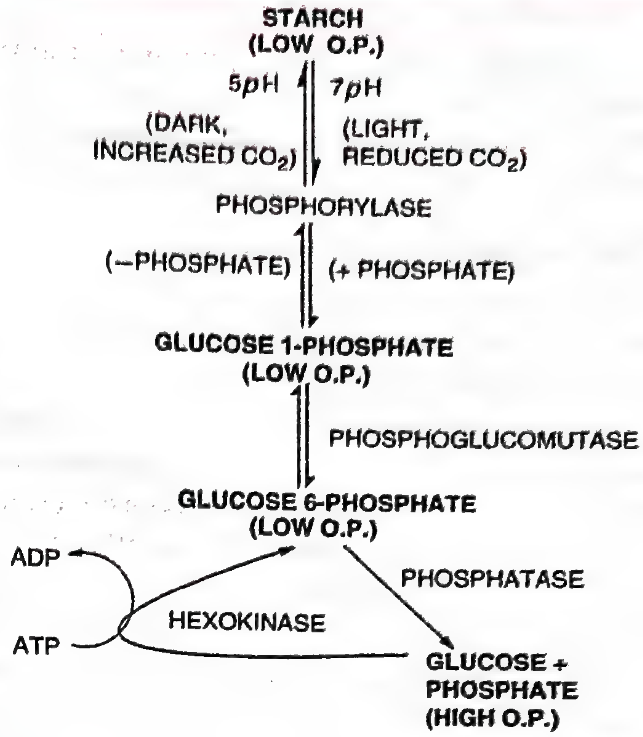


Fig. 11.36. Development of high and low osmotic pressures in guard cells through starch hydrolysis theory.

3. **Malate or K^+ ion Pump Hypothesis** (Modern Theory). The main features of the theory were put forward by Levitt (1974). According to this theory, *p*H of the guard cell can rise due to active extrusion of H^+ ions. Normally it is triggered by blue-light. Blue light sensitises **phototropin** (Briggs 2002). Phototropin passes the signal to phosphatase I (PPI). The latter activates plasmalemma based **H^+-ATPase.** It actively pumps out protons from cytosol (Shimazaki *et al* 1986). There is also uptake of H^+ ions by guard cell chloroplasts and mitochondria. CO_2 assimilation by mesophyll cells as well as guard cells. Rise in *p*H of guard cells brings about two changes. (i) It makes the interior of guard cell plasma membrane more negative. Voltage regulated potassium channels open (Schroeder *et al* 2001). K^+ ion passes inwardly passively. (ii) Starch undergoes hydrolysis to form organic acids. Out of them the most stable is malic acid. Malic acid dissociates into malate and H^+ ions. While H^+ ions are extruded, the inwardly passing K^+ ions combine with malate, pass into small vacuoles and exert an osmotic potential. Some Cl′ ions may also enter the guard cells to maintain electroneutrality.

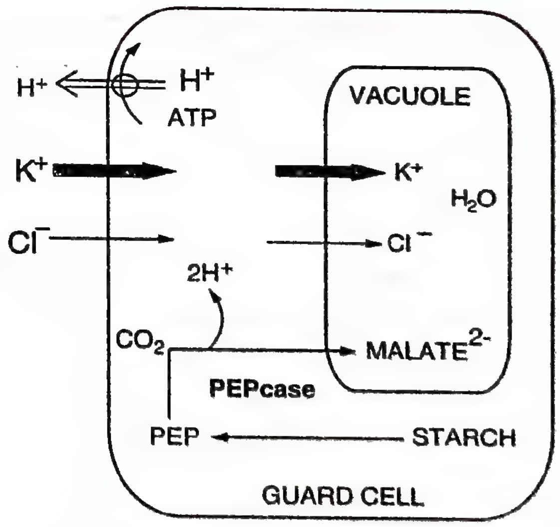


Fig. 11.37. Role of K^+, Cl^- and malate in increasing osmotic concentration (decreasing water potential) of guard cells.

High osmotic concentration of guard cells causes absorption of water from outside. The guard cells swell up and increase in volume by 40-100%%. A pore is created in between the two guard cells.

In the evening stoppage of sensitisation of phototropin causes deactivation of H^+-ATPase. Anion channels open. Chloride ion passes out. Plasmalemma depolaries. K^+ efflux channels open. Malate combines with H^+ ion to form malic acid. the latter is transformed through chemical reactions into starch.

Osmotic concentration of guard cells falls. It causes exosmosis. Turgidity of the cells falls, cell size decreases and the pore between the guard cells closes.

Stomatal closure during midday or at time of drought occurs due to formation of abscisic acid in the guard cells. It inactivates H^+-ATPase (Takamiya *et al*, 2013). Both anion and K^+-efflux channels open. It reduces osmotic concentration of guard cells, causes exosmosis of guard cells and closure of stomata.

Factors Affecting Stomatal Movements

Stomatal movements are influenced by a number of environmental factors like light, temperature, humidity, water availability and CO_2 concentration. Internal or endogenous factors include growth hormones, organic acids, K^+, Cl^- and H^+ ions.

1. **Light**. In the majority of plants the stomata open in light and close in darkness. The light intensity required for stomatal opening is quite low (250 ft candles in Tobacco). Even moon light is sufficient in some cases (Loftfield, 1921). Both red and blue parts of light are effective though the latter is slightly more effective (Mouravieff, 1958). However, in succulents or CAM plants (crassulacean acid metabolism), the stomata remain closed during daytime. They open only during dark, *e.g., Agave, Opuntia*, Pineapple.

2. **Temperature**. Q_{10} for stomatal opening is two. At 38°– 40°C, stomata can open in complete darkness, while at 0°C they remain closed even in continuous light. Normally high temperature above 30°C reduces stomatal opening in many species.

3. **Atmospheric Humidity**. In humid environment the stomata remain opened for longer periods while in dry environment they remain closed for longer periods.

4. **Water Availability**. Plants undergo water stress if availability of water is less than the rate of transpiration. Water stress (= water deficit = moisture deficit) brings about stomatal closure due to ABA and rise in DPD of epidermal cells.

5. **Mechanical Shock**. It causes closure of stomata.

6. **CO_2 Concentration**. Low CO_2 concentration usually induces opening of stomata while high CO_2 concentration closes the same. In some plants mere breathing over the leaves causes stomatal closure. However, guard cells are sensitive to CO_2 concentration only from their inner side (*i.e.*, concentration in the leaf interior). Stomata of a plant transferred to dark CO_2 free environment will remain closed but they will open in light when internal CO_2 is utilised.

7. **Oxygen**. It is essential for opening of stomata (Lougnet, 1972).

8. ***p*H**. Rise in *p*H is known to be required for opening of stomata while a fall in *p*H induces closure of stomata.

9. **Growth Hormones**. Cytokinins are essential for opening of stomata while abscisic acid takes part in stomatal closure.

10. **Minerals**. Stomatal opening depends upon availability of K^+ ions from adjacent epidermal cells. A number of other minerals are also essential for stomatal movements, *e.g.*, P, N, Mg, Ca, etc.

Expt. 12. Effect of Light, Darkness and Dehydration on Stomatal Movements.

Apparatus. Turgid leaf of a mesophytic dicot, water, strong sucrose or salt solution, slide, cover slip, blotting paper, dropper.

Working. Remove a peel or strip from the lower surface of mesophytic leaf exposed to sun. Mount the peel in water drop kept over glass slide. Place a cover slip over it. Study the peel under the microscope immediately after exposing the slide to sunlight. The peel will be seen to have a number of open stomata.

Each stomatal opening is surrounded by two bent kidney-shaped guard cells. Take the apparatus to shade. Observe after 10 minutes. The pores in between the gaurd cells have disappeared, that is, the stomata get closed. Take the apparatus again to sunlight. The stomata open again.

In the illuminated slide, remove water from below the cover slip from one end by means of blotting paper. Simultaneously, introduce concentrated sucrose or salt solution from the other end by means of dropper. When the whole of water has been replaced by concentrated solution, observe under the microscope. The stomata get closed though they are still exposed to light. Replace sucrose solution with water. The stomata open again. Allow the water to get dried. It closes the stomata.

Results. (i) Opening of stomata in light and their closing in darkness shows that light is essential for the opening of stomata. (ii) Strong sucrose or salt solution and dehydration have the same effect. The guard cells lose their turgidity and the stomata get closed.

Precautions. (i) The strip or peel should be carefully removed so that the shock effect is minimum. (ii) Keep the lower end of leaf dipping in water before use. (iii) The strip should not be left out to dry. It must be immediately dipped in water.

Factors Affecting Transpiration

External Factors (Environmental Variables)

1. **Relative Humidity**. Relative humidity is the percentage of water vapour present in the air at a given time and temperature relative to the amount required to be present to make the air saturated at that temperature. The rate of transpiration is inversely proportional to the relative humidity, *i.e.*, the rate of transpiration is higher when the relative humidity is lower and lower when the relative humidity is higher. It is because the leaf interior has a nearly saturated air in its intercellular spaces. Relative humidity of the atmospheric air governs its vapour pressure deficit or DPD or water potential. Since DPD of atmospheric air is higher at low relative humidity, more of water vapours will diffuse out of the leaf interior as compared to high RH when DPD is lower.

2. **Atmospheric Temperature**. A high temperature opens stomata even in darkness. Besides producing a heating effect, it lowers the relative humidity of the air and increases vapour pressure inside transpiring organ. For 10°C rise in atmospheric temperature vapour pressure inside leaves doubles while relative humidity decreases by 50%. Consequently, rate of transpiration increases. However, leaf temperature does not rise corresponding to rise in atmospheric temperature due to cooling effect of transpiration. Very high temperature may cause desiccation and closure of stomata. Very low temperature also closes the stomata and hence decreases the rate of transpiration.

3. **Light**. In the majority of plants stomata open in the presence of light and close in darkness. A strong light further increases transpiration probably due to its heating effect. Because most of the transpiration occurs through stomata, the rate of transpiration is quite high in light. It falls down appreciably in the darkness.

4. **Air Movements** (Wind). Transpiration is lower in the still air because water vapours accumulate around the transpiring organs and reduce the DPD of the air. The movement of the air increases the rate of transpiration by removing the saturated air around the leaves. Upto 20–30 km/hr the rate of transpiration increases with the wind velocity. A wind velocity of 40–50 km/hr decreases transpiration by closing the stomata due to mechanical effect, drying and cooling of the transpiring organs.

5. **Atmospheric Pressure**. Low atmospheric pressure enhances evaporation, produces air currents and increases the rate of transpiration.

6. **Availability of Water**. The rate of transpiration depends upon the rate of absorption of soil water by roots. This is further influenced by a number of soil factors like soil water,

soil particles, soil temperature, soil air, etc. A decrease in water uptake by the root causes partial dehydration of the leaf cells resulting in closure of stomata and **wilting.**

Wilting. It is the loss of turgidity of leaves and other soft aerial parts of a plant causing their drooping, folding and rolling. The symptoms of wilting are not shown by thick-walled tissues. Therefore, they are less conspicuous in sclerophyllous plants. Wilting is of three types: (i) **Incipient Wilting.** There are no external symptoms of wilting but the mesophyll cells have lost sufficient water due to transpiration being higher than the availability of water. It occurs during midday for a brief period in almost all plants even when sufficient water is present in the soil. (ii) **Temporary Wilting** (Transient Wilting). It is the temporary drooping down of leaves and young shoots due to loss of turgidity during noon. At this time the rate of transpiration is maximum. The rate of water absorption is less due to shrinkage of roots and depletion of water around the root hairs. Lower leaves show wilting earlier than the upper ones. Temporary wilting is corrected only after the rate of transpiration decreases in the afternoon accompanied by replenishment of water around the root hairs. (iii) **Permanent Wilting.** A permanent wilting is that state in the loss of turgidity of leaves when they do not regain their turgidity even on being placed in a saturated atmosphere. It occurs when the soil is unable to meet the requirement of plant for transpiration. Water is present in the soil largely in unavailable form (echard). At permanent wilting percentage (PWP) or coefficient (PWC) the soil contains 10–15% water depending upon its texture (about 10% in loam soil). After permanent wilting the plant dies.

Internal or Plant Factors

1. **Leaf Area** (Transpiring Area). A plant with large leaf area will show more transpiration than another plant with less leaf area. However, the rate of transpiration per unit leaf area decreases in a canopy due to density of foliage, shading effect and decrease of air movement inside the canopy.

2. **Leaf Structure**

(a) *Thickness of Cuticle.* Cuticular transpiration decreases with the thickness of cuticle and cutinisation of epidermal walls.

(b) *Number and Position of Stomata.* Because most of the transpiration takes place through the stomata, their number influences the rate of transpiration. Most dicots have stomata restricted to lower surface while the isobilateral monocot leaves possess equal number of stomata on both the surfaces.

(c) *Sunken Stomata.* The sunken stomata are device to reduce the rate of transpiration by providing an area where little air movement occurs.

(d) *Stationary Layer and Hair.* The hair insulate the surface of the leaf from air currents and air temperature. They hold a **stationary layer** of air (also called boundary layer). The thicker the boundary or stationary layer, the lower is the rate of transpiration. It is because the leaf will first lose water to stationary layer and from there it would travel to the outside.

(e) *Mesophyll.* Compact mesophyll (as having more of palisade tissue and fewer intercellular spaces) reduces transpiration while a loose mesophyll (having more of spongy tissue and larger intercellular spaces) increases transpiration.

(f) *Leaf Modifications.* Formation of prickles, leaf spines, scaly leaves, phyllodes, phylloclades (instead of leaves), are all modifications found in xerophytes to reduce transpiration. In xerophytes the leaves are also smaller (to reduce the effect of heating) and leathery (to prevent wilting).

3. **Root/Shoot Ratio.** A low root/shoot ratio decreases the rate of transpiration while a high ratio increases the rate of transpiration. The latter is due to the fact that an extensive root system is more efficient in water uptake from soil. Increased availability of water also increases transpiration.

4. **Mucilage and Solutes.** They decrease the rate of transpiration by holding water tenaciously.

Significance of Transpiration

Advantages

1. **Ascent of Sap.** Ascent of sap mostly occurs due to transpiration pull exerted by transpiration of water. This pull also helps in absorption of water.

2. **Removal of Excess Water.** It has been held that plants absorb far more amount of water than is actually required by them. Transpiration, therefore, removes the excess of water.

3. **Cooling Effect.** Radiant heat falling on the plants increases their temperature which may be dangerous to the plants. Transpiration, by evaporating water, lowers down their temperature by 10°–15°C.

4. **Mechanical Tissue.** The development of mechanical tissue, which is essential for providing rigidity and strength to the plant, is favoured by the increase in transpiration.

5. **Distribution of Mineral Salts.** Mineral salts are mostly distributed by rising column of sap.

6. **Increasing Concentration of Mineral Salts.** The sap absorbed from the soil contains low concentration of mineral salts. The loss of water through transpiration increases the concentration of mineral salts in the plant.

7. **Root System.** Transpiration helps in better development of root system which is required for support and absorption of mineral salts.

8. **Quality of Fruits.** The ash and sugar content of the fruit increases with the increase in transpiration.

9. **Resistance.** Excessive transpiration induces hardening and resistance to moderate drought.

10. **Turgidity.** Transpiration maintains the shape and structure of plant parts by keeping cells turgid.

11. **Photosynthesis.** Transpiration supplies water for photosynthesis. As water evaporates through the stomata, it results in pulling of water, molecule by molecule into the leaf from the xylem.

Disadvantages

1. **Wilting.** Wilting or loss of turgidity is quite common during noon due to transpiration being higher than the rate of water absorption. Wilting reduces photosynthesis and other metabolic activities.

2. **Reduced Growth.** Transpiration reduces availability of water inside the plant. Water deficit decreases growth and hence the plant gives a stunted appearance.

3. **Reduced Yield.** As reported by Tumarov (1925), a single wilting reduces growth by 50%. It is because decreased availability of water inside the plant checks meristematic activity and hence the formation of flowers, fruits and seeds.

4. **Abscisic Acid.** Water stress produces abscisic acid. Abscisic acid prevents several plant processes and promotes abscission of leaves, flowers and fruits.

5. **Wastage of Energy.** Since 98–99% of absorbed water is lost through transpiration, the energy used in absorption and conduction of water goes waste.

6. **Modifications.** In order to reduce transpiration during critical periods, the plants produce several types of modifications— thick cuticle, hair, prickles, spines, thorns, sunken stomata, phylloclades, cladodes, etc.

Nevertheless transpiration cannot be checked. Stomatal transpiration will always occur whenever stomata are open for gaseous exchange (so essential for photosynthesis and respiration). Similarly cuticular and lenticular types of transpiration cannot be checked as there is no method of their control. Hence transpiration is regarded as a **necessary evil** (Curtis, 1926) or **unavoidable evil** (Steward, 1959).

Transpiration and Photosynthesis— a compromise

(Water Requirement)

The amount of water transpired per unit of dry matter manufactured by a plant is called **water requirement, transpiration ratio** or efficiency of transpiration (Lowes, 1850). It is minimum for crassulacean or succulent plants, moderate in C_4 plants and maximum in C_3 plants. The common value is 300 – 600. In CAM plants, it is about 50. C_3 plants transpire the maximum. Humidity of rain forests is due to large scale water lost by plants. It results in condensation and local rain. C_3 plants lose 600 – 900 grams of water for one gram of dry matter synthesized. It is because they have high sponginess of their mesophyll tissue due to presence of fine spaces in between the palisade cells and larger spaces in between the spongy parenchyma cells.

C_4 plants have evolved a strategy to maximise availability of CO_2 and minimise the water loss. Their transpiration ratio is 300. C_4 plants are twice as efficient as C_3 plants in terms of fixing carbon. However, a C_4 plant loses only half as much water as a C_3 plant for the same amount of CO_2 fixed. CAM plants do not open their stomata during the day. They also store water. The plants absorb and store carbon dioxide during night when transpiration loss is minimum. The absorbed CO_2 is used in photosynthesis during the daytime. The value indicates the requirement of irrigation and rain. In areas where irrigation is not adequate and the rainfall is also not heavy, those crops and plants can be grown which have low water requirement. Thus Sorghum, Bajra and Ragi are useful for growth in these rainfed crop lands. The trees include *Dalbergia sisso*, Margosa (Neem), *Acacia, Prosopis*. When irrigation is assured, the suitable crops are Tomato, Sugarcane and Rice. Areas with good rainfall may be used for growth of Bamboo, Rose-wood, Willow, Teak, Arecanut, Coconut, Coffee and Tea.

Transpiration – a price paid for photosynthesis

Most of the plant physiologists hold the view that transpiration is a price which the plant pays for photosynthesis. As the stomata open in the light for gaseous exchange (CO_2 for photosynthesis and O_2 for respiration) water vapours escape side by side. When stomata are closed in dark, loss of water is minimum through transpiration. This means that transpiration occurs alongwith photosynthesis. For this reason, it is said that transpiration is the price which the plant pays for photosynthesis.

Antitranspirants

During drought conditions the plants show wilting. According to Tumarov (1925) a

single wilting reduces plant yield by 50%. In arid and unirrigated areas crop plants cannot be grown because of excessive transpiration and reduced water availability. *Substances that reduce the rate of transpiration are called antitranspirants.* Antitranspirants will maintain a favourable internal water balance even in cases of very low water availability. It will allow farmers to grow crops profitably in unirrigated areas and help foresters to plant trees even in extreme arid or desert areas. Antitranspirants are of two types, metabolic inhibitors and surface films.

Metabolic inhibitors reduce transpiration by reducing the stomatal opening for a period of two or more weeks without influencing other metabolic processes. The most promising of these inhibitors is phenyl mercuric acetate (PMA, 10^{-4}M). Another is abscisic acid (ABA or AbA).

Film forming chemicals check transpiration by forming a thin film on the transpiring surface. They are sufficiently permeable to carbon dioxide and oxygen to allow photosynthesis and respiration but prevent movement of water vapours through them. The important chemicals of this group are silicon emulsions, colourless plastic resins and low viscosity waxes. However, antitranspirants are still in experimental stage.

GUTTATION

The loss or excretion of water in the form of liquid droplets from the leaves and other parts of an uninjured or intact plant is called **guttation**. It was first studied by **Bergerstein** in 1887. All plants do not show guttation. It is restricted to about 345 genera of marshy and mesophytic herbaceous and some woody plants. Common examples are found in Garden Nasturtium, Oat and other cereals, Balsam, Tomato, Cucurbits.

Expt. 13. Demonstration of Guttation

Apparatus. A well watered potted plant of Garden Nasturtium or Oat, a bell jar, glass slab, vaseline.

Place a well watered potted plant of Garden Nasturtium or Oat under a bell jar over a flat surface preferably a glass slab. Seal the edges of the bell jar by vaseline. Within an hour small droplets of liquid water will be observed at the leaf margins (Garden Nasturtium, Fig. 11.38A) or leaf tips (Oat, Fig. 11.38 B).

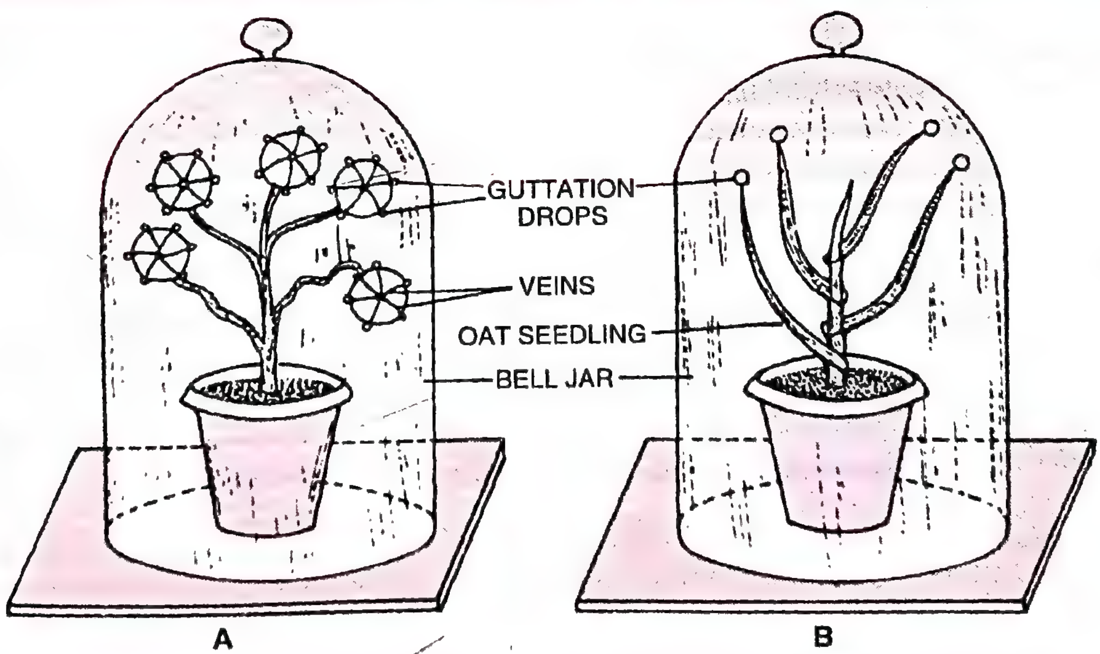


Fig. 11.38. Demonstration of guttation in A, Garden Nasturtium; B, Oat.

The guttated liquid is never pure water. It contains 0.6–2.5 gm/litre of solutes— both organic (carbohydrates, organic acids, amino acids, enzymes) and inorganic (Ca^{2+}, Mg^{2+}, K^+, Na^+, CO_3^{2}, SO_4^{2-}, Cl^-). Evaporation of guttated liquid will leave the solutes on the surface of the leaf in the form of a white crust (another reason for the latter is excretion of salts in some halophytes). Guttation usually occurs during periods of active growth when conditions favour more water absorption and less transpiration. Such conditions are found in humid tropical areas, rainy seasons and late spring in temperate areas. Guttation takes place either at night or early in the morning. Dry soils, poorly aerated soils, heavily salted or mineral deficient soils and the atmospheric conditions promoting transpiration inhibit guttation.

Guttation drops can easily be mistaken for dew drops because both occur in the morning. However, dew generally does not fall on cloudy nights. Further guttation drops are restricted to tips or margins of the leaves while dew drops are found all over the plant and even the soil.

Guttation takes place through special structures called **hydathodes** (Fig. 11.39). They are usually found on the margins and tips of the leaves. Each hydathode consists of a group of loosely arranged achlorophyllous or colourless and parenchymatous cells called **epithem.** It lies over the tip of a vascular strand and communicates with the outside through a permanent pore in the epidermis called **water pore** or **water stoma**. The term hydathode is also applied to water pore. Exudation of liquid from the water pore or stoma is due to the development of a positive pressure in the xylem present in the vein ending. The pressure forces the liquid out through the hydathode. The epithem cells are specialized cells (called transfer cells) which help in absorbing a good percentage of inorganic and organic solutes present in the exudate. However, a part of these solutes do come out of the hydathode alongwith the liquid.

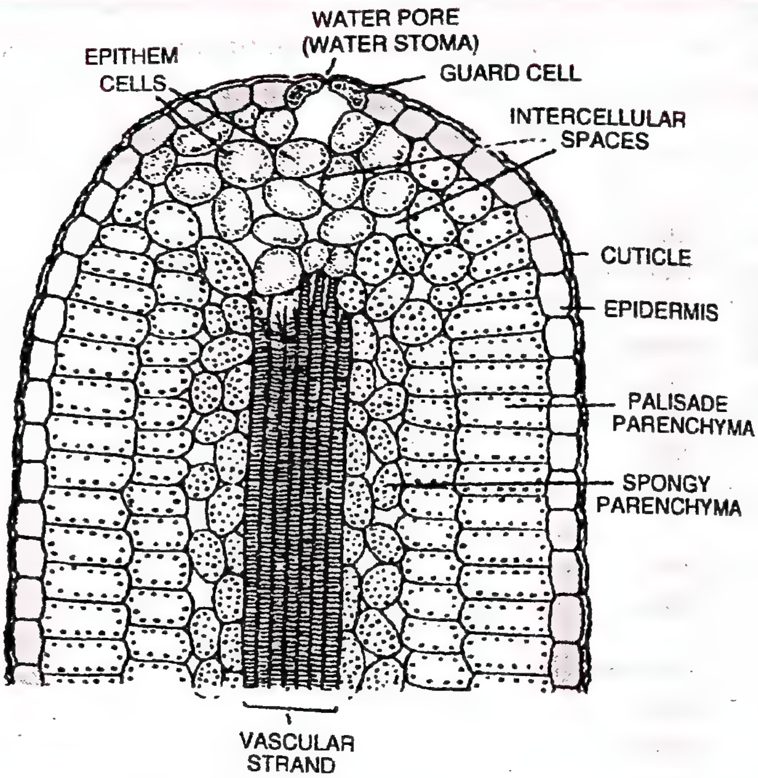


Fig. 11.39. Section of leaf showing hydathode.

Bleeding

It is the exudation of sap or watery solution from the cut or injured parts of the plant, *e.g., Agave, Acer, Vitis*, Toddy Palm. It occurs due to root pressure, phloem pressure, local pressure in xylem (stem pressure) and latex or resin.

Differences between Transpiration and Guttation

Transpiration	*Guttation*
1. It is the loss of water by a plant in the form of vapours.	1. Guttation is the loss of liquid droplets from the plant.
2. The transpired water is pure water.	2. Guttated water is a dilute solution of both inorganic and organic substances.

3. Transpiration occurs through the general surface of the leaves and the young stems.	3. Guttation commonly occurs at the margins and the tips of the leaves.
4. It does not leave anything on the surface of the plant.	4. An incrustation of salts is formed on the surface after the guttated liquid evaporates.
5. Most of the transpiration occurs during the hotter periods of the day. It is negligible during night.	5. Guttation mostly occurs during night and early hours of the morning.
6. Transpiration occurs through stomata, lenticels and epidermal cells.	6. Guttation occurs only through water pores.
7. Stomata can be opened or closed.	7. The water pore is always kept open.
8. Transpiration causes the development of a negative pressure in the xylem of the plant.	8. Guttation is produced only when the xylem shows a positive pressure.
9. It occurs during dry periods.	9. Guttation takes place during humid periods.
10. Transpiration continues even when the plant is under water stress.	10. It does not occur under conditions of water deficiency.
11. Excessive transpiration produces wilting.	11. Excessive guttation does not cause loss of turgidity.

Differences between Stomata and Hydathodes

Stomata	*Hydathodes*
1. Stomata are found in the aerial parts of all land plants.	1. Hydathodes occur on the leaves of only a few plants.
2. They are found on the surfaces of both the leaves and the young parts of the stem, flowers, fruits, etc.	2. Hydathodes occur on the margins and tips of the leaves.
3. Guard cells may be surrounded by subsidiary cells.	3. Subsidiary cells are absent.
4. Guard cells contain chloroplasts.	4. Cells bordering a water pore are usually achlorophyllous.
5. The stomata can be opened or closed by the turgor changes in the guard cells.	5. Hydathodes possess permanent pores because the guard cells surrounding them are immobile.
6. Stomata pass out water vapours.	6. Haydathodes send out liquid water.
7. Alongwith water vapours, stomata allow passage of CO_2 and O_2.	7. Small quantities of solutes also pass out dissolved in guttated liquid.
8. Each stomate leads internally to a substomatal cavity.	8. Hydathode possesses loosely arranged epithem cells below its pore.
9. They do not have any connection with a vein ending.	9. Hydathodes contain a vein ending.

Mineral Uptake by Roots

Plants obtain their supply of carbon and most of their oxygen from CO_2 of atmosphere, hydrogen from water while the rest are minerals which are picked up individually from the soil. Minerals exist in the soil as **ions** which cannot directly cross the cell membranes. The concentration of ions is some 100 times more in root interior than in the soil. Therefore, all minerals can not be passively absorbed. The movement of ions from soil to interior of root is against concentration gradient and requires an **active transport**. Specific **ion pumps** occur in the membrane of root hairs. They pump mineral ions from soil to cytoplasm of epidermal cells of root hairs. Energy is provided by ATP. Respiratory inhibitors like cyanide which inhibit ATP synthesis, generally reduce the ion uptake. The small amount which passes

into the root even without ATP, must be through a passive technique. For active transport, ATPases are present over the plasma membranes of root epidermal cells. They establish an **electrochemical proton gradient** for supplying energy for movement of ions. The ions are again checked and transported inwardly by **transport proteins** present over the endodermal cells. Endodermis allows the passage of ions inwardly but not outwardly. It also controls the quantity and type of ions to be passed into xylem. Inward flow of ions from epiblema to xylem is along the concentration gradient. The collection of ions in the xylem is responsible for water potential gradient in the root that helps in osmotic entry of water as well as its passage to xylem. In the xylem, minerals are carried up alongwith the flow of xylem solution. In leaves the cells absorb the minerals selectively through membrane pumps (Fig. 11.21).

Translocation of Mineral Ions in the Plant

Though it is generally considered that xylem transports inorganic nutrients while phloem transports organic nutrients, the same is not exactly true. In xylem sap, nitrogen travels as inorganic ions, as well as organic form of amino acids and related compounds. Small amounts of P and S are passed in xylem as organic compounds. There is also exchange of materials between xylem and phloem. Therefore, mineral elements pass up xylem in both inorganic and organic form. They reach the area of their sink, namely young leaves, developing flowers, fruits and seeds, apical and lateral meristems and individual cells for storage. Minerals are unloaded at fine vein endings through diffusion. They are picked up by cells through active uptake.

There is remobilization of minerals from older senescing parts. Nickel has a prominent role in this activity. The senescing leaves send out many minerals like nitrogen, sulphur, phosphorous and potassium. Elements incorporated in structural components are, however, not remobilised, *e.g.*, calcium. The remobilised minerals become available to young growing leaves and other sinks.

Phloem Transport : Flow from Source to Sink

It is the long distance movement of organic substances from the **source** or supply end (region of manufacture or storage) to the region of utilization or **sink**. But the source and sink may be reversed depending on the season or need of the plants. Sugar stored in roots may be mobilised to become a source of food in the early spring when the buds of trees act as sink and require energy for their growth and development. Since the source–sink relationship is variable, the direction of movement of organic solutes in phloem can be upwards or downwards *i.e., bidirectional* (c.f. unidirectional upwards in xylem).

Photosynthesis Regions → Nonphotosynthetic Regions

↘ ↗

Storage Regions

Directions of Translocation of Organic Solutes

Translocation of organic solutes can occur in the following directions :

1. **Downward Translocation**. It is the most common mode of translocation. The leaves manufacture food in excess of their own requirement. The excess food comes out of leaves and is translocated in the downward direction to stem (for storage, metabolism, maintenance of its cells and secondary growth, if any) and root system (for storage, growth, metabolism and maintenance).

2. **Upward Translocation**. In deciduous plants renewal of growth and development of

new foliage are dependent upon upward transport of food from reserves present in the roots and stems. Growth of the stem apices, formation of flowers, fruits, etc. require the movement of assimilates from leaves in an upward direction.

3. **Lateral Translocation.** It is little except when source and sink lie on the opposite sides (Peel, 1964).

4. **Bidirectional Translocation.** Rabideau and Burr (1945) found that labelled carbohydrates moved out of the leaves in both upward and downward directions. The two types of translocation are believed by many workers to occur in different sieve tubes.

Differences between Diffusion and Translocation

Diffusion	*Translocation*
1. It occurs in all directions through the available space.	1. It is directional movement of materials.
2. A vascular tissue is not required.	2. It occurs inside vascular tissues.
3. Diffusion is a slow process.	3. Translocation is a rapid process.
4. Diffusion occurs at the particulate level.	4. Translocation is passage of materials in bulk.

Pathway of Translocation

The most common organic nutrient translocated in plants is sucrose. The channels of transport are sieve tubes (in flowering plants) and sieve cells (in nonflowering vascular plants) of phloem. It was proved for the first time by Czapek (1897). The evidences are as follows :

1. There are only two paths for long distance translocation, tracheary elements and sieve tubes. The former are dead while the latter are living. Translocation of organic solutes seems to be through sieve tubes because it is inhibited by steam girdling which kills living cells.

2. In **girdling** or **ringing** experiments (Malpighi, 1675), a ring of bark is cut from the stem. It also removes phloem. Nutrients collect above the ring where the bark also swells up and may give rise to adventitious roots (Fig. 11.40). Growth is also vigorous above the ring. The tissues below the ring not only show stoppage of growth but also begin to shrivel (Roots can be starved and killed if the ring is not healed after some time. Killing of roots shall kill the whole plant) clearly showing that bark or phloem is involved in the movement of organic solutes which occurs in one direction, *i.e.*, towards root.

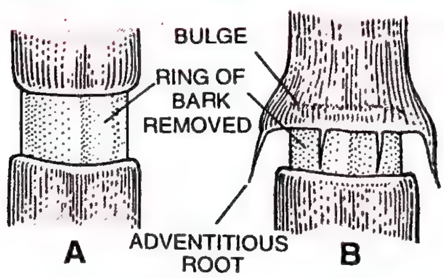


Fig. 11.40. Girdling of tree trunk to show that organic nutrients accumulate in the bark above the girdle where a bulge is also produced.

Girdling experiments are performed in fruit trees to make more food available to fruits. However, the rings are kept narrow and cambium is not touched so that the incision heals up after some time. (Girdling experiments cannot be carried out in monocots and dicots with bicollateral bundles because of the absence of a single strip of phloem).

3. Mason and Maskell (1928) inserted a wax paper between phloem and xylem. Parts of the bark were also removed except for a narrow strip. They found evidence that the organic solutes passed through the narrow strip of bark containing the phloem.

4. By means of **aphid stylets,** Weatherley *et al* (1959) found that sieve tubes contained a concentrated solution of organic substances under a pressure.

5. Radio-autographs show that assimilates with incorporated radioactive elements pass out of the leaves and travel towards the sink ends through phloem.

6. Sieve tubes contain contain an alkaline phloem sap having a high organic solute content— 5–10% soluble carbohydrates (mostly surcose), about 1% nitrogenous compounds (mostly amino acids), organic acids besides traces of hormones and other organic solutes. Sucrose is most suitable form of carbohydrate translocation as it is nonreducing and chemically stable. It does not react with other substances during translocation.

7. Tonoplast is absent in sieve tube cells so that cytoplasm is in direct contact with vacuolar contents.

8. Sieve tube cytoplasm can tolerate high concentration of solutes without being plasmolysed.

9. Cytoplasm of one sieve tube cell is continuous with that of the adjacent sieve tube cells through sieve plates so as to form continuous filaments. The centre of sieve tube cells is empty with cytoplasmic strands being peripheral.

10. Sieve tube cells possess granules and filaments of P-protein with ATP-ase activity.

11. Relatively large amounts of organic solutes are translocated. The rate of translocation of organic nutrients is such that a sieve tube must be refilled 3–10 times per second (Zimmermann, 1964). Crafts and Lorenz (1944) found that a pumpkin fruit receives 5500 gm of the organic solution in 33 days with a rate of 0.61 gm of dry weight or translocation of 110 cm per hour.

12. Lateral movement from phloem to living cells or from source to phloem occurs through transfer cells and symplasm.

Mechanism of Phloem Translocation

Several theories have been put forward to explain the mechanism of translocation of organic nutrients through the phloem *e.g.*, diffusion, activated diffusion, protoplasmic streaming, interfacial flow, electrosmosis, transcellular strands, contractile proteins, mass flow. Mass flow hypothesis is the most accepted one.

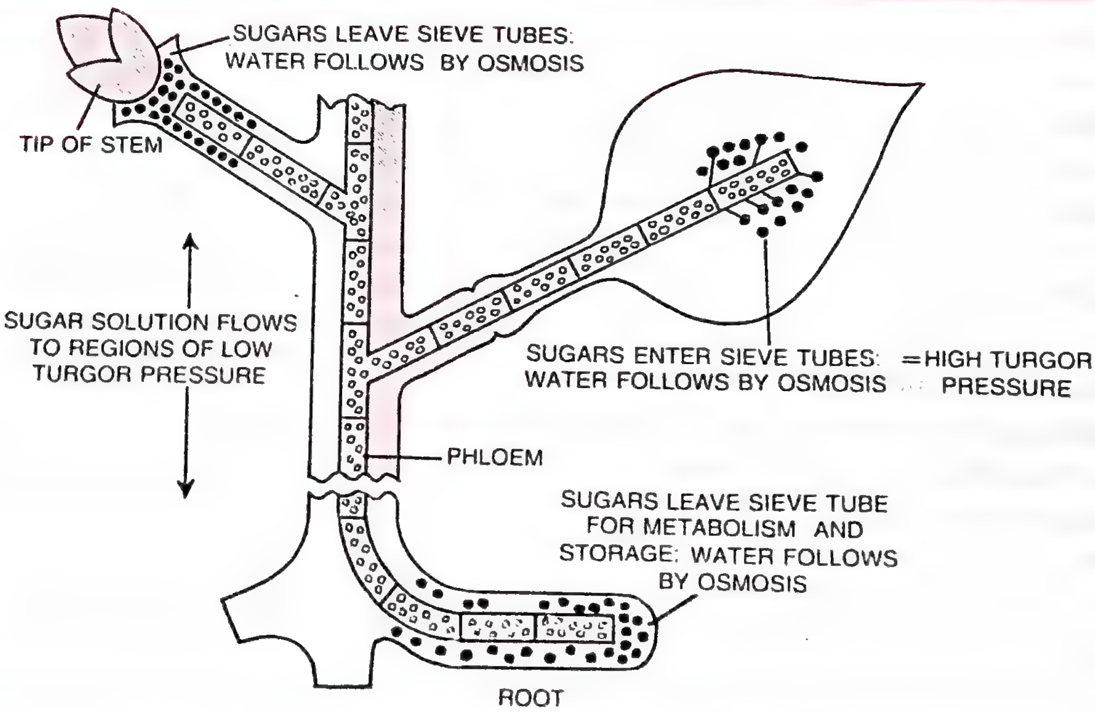


Fig. 11.41. Pathway and mechanism of phloem translocation.

Mass Flow or Pressure Flow Hypothesis. It was put forward by Munch (1927, 1930). According to this hypothesis, organic substances move from the region of high osmotic pressure to the region of low osmotic pressure in a mass flow due to the development of a gradient of turgor pressure (Fig. 11.41). This can be proved by taking two interconnected

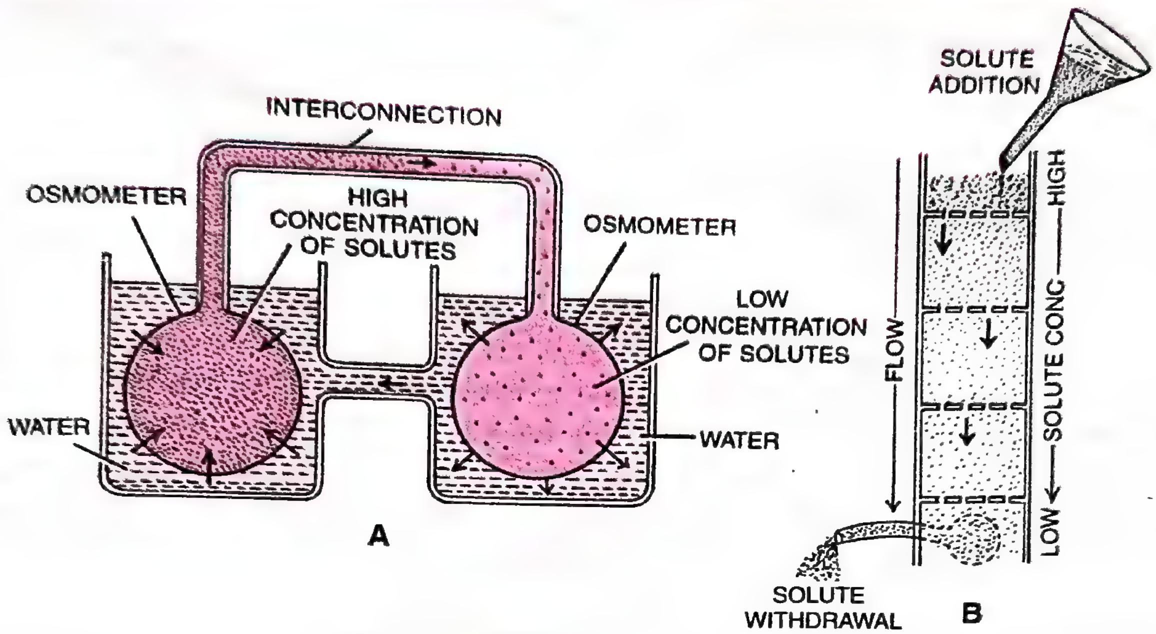


Fig. 11.42. A, mass flow or pressure flow of fluids from high to lower osmotic or turgor pressure. B, diagrammatic representation of continuous flow of solutes in one direction.

osmometers, one with high solute concentration and the other with little osmotic concentration. The two osmometers of the apparatus are placed in water (Fig. 11.42). More water enters the osmometer having high solute concentration as compared to the other. It will, therefore, come to have high turgor pressure which forces the solution to pass into the second osmometer by a mass flow. If the solutes are replenished in the donor osmometer and immobilised in the recipient osmometer, the mass flow can be maintained indefinitely.

Sieve tube system is fully adapted to mass flow of solutes. Here the vacuoles are fully permeable because of the absence of tonoplast (Esau, 1966). A continuous high osmotic concentration is present in the source or supply region, *e.g.*, mesophyll cells (due to photosynthesis). The organic substances present in them are passed into the sieve tubes through intermediate, transfer and companion cells by an active process.

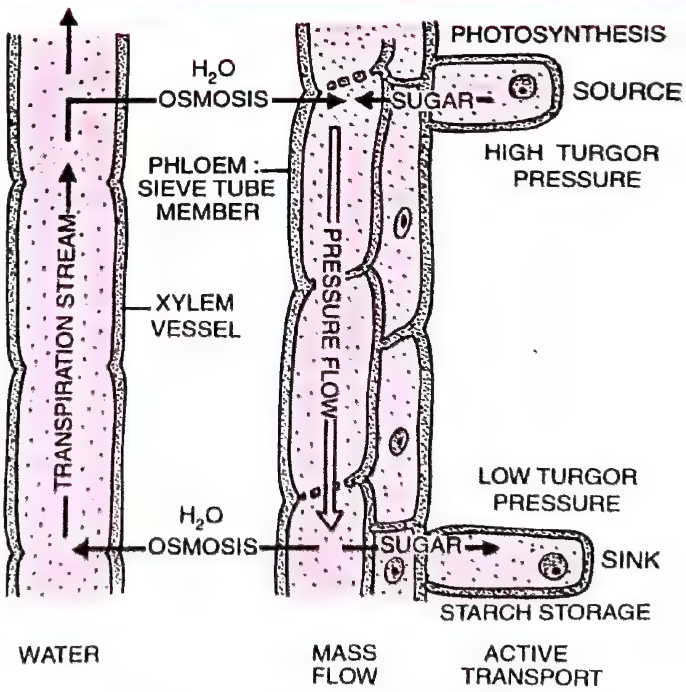


Fig. 11.43. Translocation of organic substances (assimilates) according to mass flow or pressure flow hypothesis.

A high osmotic concentration, therefore, develops in the sieve tubes of the source. The sieve tubes absorb water from the surrounding xylem and develop a high turgor pressure (Fig. 11.43). It causes the flow of organic solution towards the area of low turgor pressure. A low turgor pressure is maintained in the sink region by converting soluble organic substances into insoluble form. Water passes back into xylem.

Evidences. (i) Sieve tubes contain organic solutes under a pressure because an injury causes exudation of solution rich in organic solutes. (ii) Direction of flow of organic solutes is always towards concentration gradient. A fall of 20% concentration was observed by Zimmermann (1957) over a distance of eight metres. (iii) Defoliation of shoots causes disappearance of concentration gradient in its phloem. (iv) Bennet (1937) observed viruses to move in phloem in a mass flow in the direction of movement of organic solutes at a rate of about 60 cm/hr. (v) All the substances dissolved in sieve tubes are found to move with the same velocity with minor differences. (vi) The hypothesis can be simulated experimentally.

Objections. (i) Vacuoles of the adjacent sieve tube cells are not continuous. The cytoplasm present near the sieve plates exerts resistance to the mass flow. (ii) Catalado *et al* (1972) have observed that the rate of flow of water (72 cm/hr) and solutes (35 cm/hr) to be different in the same sieve tube. (iii) Phloem transport is not influenced by water deficit. (iv) The cells at the source end of mass flow should be turgid but they are often found to be flaccid in case of germinating tubers, corms, etc.

ADDITIONAL INFORMATION

- **Molar Solution.** It is a solution having 1 gm mole of a solute dissolved in 1 litre of solution. Molar solution is also called **volume molar solution.**
- **Molal Solution.** It is a solution having 1 gm mole of a solute dissolved in 1 litre of solvent. Molal solution is also called **weight molar solution.**
- **Zero Values.** DPD or Ψw is zero in a fully turgid cell placed in water. Turgor pressure (TP) or pressure potential becomes zero when a cell is placed in hypertonic solution. Osmotic pressure cannot become zero in a cell. It is zero only in case of pure water.
- **Matric Potential** (Imbibition Potential). It is the reduction in chemical potential of water due to imbibition by hydrophilic colloids.
- **Psychrometer.** It is an instrument for measuring both relative humidity and transpiration.
- **Relative Humidity and Stomata.** Stomata close down if relative humidity of atmosphere falls below 50%. They remain open at R.H. above 70%.
- **Schwendener** (1881). First to propose that stomatal movements are due to turgor changes in the guard cells.
- **Photoactive and Scotoactive Stomata.** Stomata opening in response to presence of light are called photoactive stomata, while the ones opening in dark are called scotoactive stomata.
- **Stephen Hales.** Father of Plant Physiology who also coined the term root pressure.
- **Tensiometer.** Instrument that measures soil water tension.
- **Auxin and Active Water Absorption.** Auxin treated cells can absorb a water even from hypertonic solution, apparently through an active process.
- **Absorption Lag** (Kramer, 1937). It is the short fall of rate of water absorption over the rate of transpiration. It is due to high rate of transpiration during midday, development of water deficit around root hairs and resistance in the movement of water inside the plant.
- **Tensile Strength of Water.** It is the ability of water column to get stretched without breaking. The value is 45-207 atm (Dixon and Joly, 1894). Tensile strength is due to cohesive force amongst molecules of water and adhesion between water molecules and walls of xylem.
- **Atmometer.** It is an apparatus for demonstrating and measuring pull caused by evaporation of water from a porous pot.
- **Wilting and Water-logging.** In water-logged soils the plants often show wilting. It is

caused by development of ethylene precursor by the roots (Bradford and Young, 1981) which reaching the shoot brings about wilted condition.

- **Potometer**. It is an apparatus for measuring the rate of transpiration.
- **Porometer**. It is an apparatus for knowing the relative sizes of stomata.
- **Cytoplasmic Streaming.** It is movement of cell cytoplasm in eukaryotes, *e.g., Hydrilla* leaf cells, *Tradescantia* (=Rhoeo) staminal hair.
- **Stomatal Index. It is ratio of number of stomata to the total number of epidermal cells and stomata (E+ S) per unit leaf area. It is fixed for a species.**
- **The term** hydathode **is also applied to water pore.**

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. What are the factors that affect the rate of diffusion ?
✓ (i) Density of the substance. (ii) Density or permeability of the medium. (iii) Temperature (iv) Diffusion pressure. (v) Distance.

2. What are porins ? What role do they play in diffusion ?
✓ **Porins** are proteins lined hydrophilic channels present in the outer membrane of plastids, mitochondria and some bacteria. They allow passage of large biomolecules, even small sized proteins as per diffusion gradient. **Aquaporins** are water channels for diffusion of water molecules across the plasma membrane as per osmotic gradients.

3. Describe the role played by protein pumps during active transport in plants.
✓ **Protein Pumps** are carrier proteins which take part in transport of solutes across the cell membrane with the help of energy even against concentration gradient. Energy is supplied by ATP. On being activated with energy, the protein pump picks up solute particles from outside and throw the same to the inner side into the cytoplasm. There are a number of pumps, *e.g.,* $Na^+ - K^+$ pump, Ca^{2+} pump.

4. Explain why pure water has the maximum water potential ?
✓ Water potential is chemical potential or free energy of water in molal unit volume in a system. Pure water has the maximum number of free water molecules as well as the amount of the free energy decreases with the addition of solute particles. The degree of decrease of water potential in a solution depends upon the number of solute particles. By convention water potential of pure water is taken as zero. Its value becomes negative with addition of solute particles. Therefore, pure water has the maximum water potential.

5. Briefly describe water potential. What are the factors affecting it ?
✓ **Water potential** is the difference in chemical potential per unit molal volume of water in a system and that of pure water at the same temperature and pressure. By convention water potential of pure water is taken as zero. Its value becomes negative in a solution as the solute particles reduce the chemical potential of water by decreasing its free energy.
Factors. (i) Solute potential (Ψs). (ii) Pressure potential Ψp. (iii) Matric potential (Ψm due to colloidal particles). (iv) Temperature. (v) Pressure (vi) Loss or gain of water.

6. What happens when a pressure greater than the atmospheric pressure is applied to pure water or a solution ?
✓ Pressure applied to pure water or a solution is a positive pressure that will increase the diffusivity of water whether in pure water or in solution. In solution it will reduce or prevent the entry of water from outside. If the solution is very dilute, pressure can cause reverse osmosis.

7. (a) With the help of well labelled diagrams, describe the process of plasmolysis in plants giving appropriate examples.
(b) Explain what will happen to a plant cell if it is kept in a solution having higher water potential ?
✓ (a) Plasmolysis is a shrinkage of protoplast from the cell wall under the influence of hypertonic solution. This can be observed by placing of fresh filament of *Spirogyra* or fresh peel from the lower surface of *Rhoeo (= Tradescantia)* in a 10% solution of common salt. The cells undergo exosmosis. Loss of water results in shrinkage of protoplast accompanied by shrinkage of cell size. Later protoplast will separate from the wall first at the corners (incipient plasmolysis) and then from other parts (evident plasmolysis) except for certain points in the region of plasmodesmata, if present. (Fig. 11.17)

(b) Higher water potential occurs in a hypotonic or dilute solution. A plant cell present in such a solution will absorb water due to endosomosis. It will become turgid or swollen. The swelling protoplast develops a wall pressure that becomes equal to water potential of the system. At this time further endosmosis stops.

8. What role does root pressure play in water movement in plants ?
✓ (i) Being a positive pressure, it meets the water deficit of the cells created due to transpirational loss.
(ii) Certain workes believe that root pressure helps in ascent of water in small-sized plants.
(iii) It dissolves and removes the air bubbles formed during transpiration pull.

9. Describe transpiration pull model of water transport in plants. What are the factors influencing transpiration ? How is it useful to plants ?
✓ **Transpiration Pull Model.** Describe cohesion-tension theory of Dixon and Joly (1894).
Factors Influencing Transpiration. Refer to the text.
Uses of Transpiration. Refer to the text advantages under significance of transpiration.

10. Discuss the factors responsible for ascent of xylem sap in plants.
✓ The various factors responsible for ascent of sap are as follows : (i) **Capillarity.** It is limited rise of water in narrow tubes or capillaries due to forces of cohesion amongst molecules of water and their property of adhesion to other substances. (ii) **Imbibition.** It is the ability of hydrophilic colloids to attract and hold water on the surface and inside their interspaces. (iii) **Root Pressure.** It is positive pressure that pushes sap from below due to active absorption by root. (iv) **Transpiration Pull.** Transpiration in aerial parts brings the xylem sap under negative pressure or tension due to continuous withdrawal of water by them. Water column does not break due to its high tensile strength related to high force of cohesion and adhesion.

11. What essential role does the root endodermis play during mineral absorption in plants ?
✓ Endodermis has two essential roles in mineral absorption. (i) It regulates the movement of minerals passing into vascular strand due to presence of casparian strips. Minerals have to pass through symplast pathway and then special sets of carrier proteins and ion channels present in the plasma membrane of endodermal cells. (ii) Endodermis does not allow the flow of minerals back from vascular strand into cortex of root.

12. Explain why xylem transport is unidirectional and phloem transport bidirectional.
✓ Direction of transport is determined by the sink or area of utilisation of the material under transport.
Unidirectional Xylem Transport. Xylem transport is unidirectional and upwards from roots to shoot tips. The force for upward movement develops in the aerial parts due to loss of water in transpiration. It creates a tension or negative pressure in the water column. The latter is, therefore, pulled upwards.
Bidirectional Phloem Transport. Organic nutrients are loaded in the phloem in the region of manufacture (*e.g.,* leaves) or storage. It draws water into the area creating a high turgor pressure. A low turgor pressure exists in the area of utilisation of nutrients (*e.g.,* roots, shoot tips) because of regular withdrawal. Transport occurs both in the downward and upward directions from the leaves due to gradient of turgor pressure.

13. What causes the opening and closing of guard cells of stomata during transpiration ?
✓ Opening and closing of stomata occurs due to influx and efflux of K^+ ions into or out of guard cells. For details Refer to the text.

14. Differentiate between the following : (a) Diffusion and Osmosis, (b) Transpiration and Evaporation, (c) Osmotic Pressure and Osmotic Potential, (d) Imbibition and Diffusion, (e) Apoplast and Symplast pathways of movement of water in plants, (f) Guttation and Transpiration.
✓ (a) **Differences between Diffusion and Osmosis.** Refer to the text.
(b) **Differences between Transpiration and Evaporation.** Refer to the text.
(c) **Differences between Osmotic Pressure and Osmotic Potential.** Refer to the text.
(d) **Differences between Imbibition and Diffusion.** Refer to the text.
(e) **Differences between Apoplast and Symplast Pathway of Movement of Water in Plants.** Refer to the text.
(f) **Differences between Guttation and Transpiration.** Refer to the text.

15. How is mycorrhizal association helpful in absorption of water and minerals in plants ?
✓ Refer to the text under mycorrhizal water absorption.

16. Explain pressure flow hypothesis of translocation of sugars in plants.
✓ Refer to the text.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Which of the following has highest water potential ?
   (i) IM Salt solution (ii) IM Sugar solution (iii) Distilled water (iv) IM Sugar solution with 2–3 bars pressure.
   ✓ Distilled water.
2. Which fraction of soil water is available to plants for absorption by roots ?
   ✓ Capillary water
3. Expand DPD ?
   ✓ Diffusion Pressure Deficit .
4. What will happen if a plant cell is kept in solution of higher water potential ?
   ✓ Endosmosis.
5. What will happen if a plant cell is kept in hypotonic solution for some time ?
   ✓ Endosmosis.
6. A plant cell kept in certain solution got plasmolysed. What was the nature of the solution ?
   ✓ Hypertonic.
7. Why is energy required to develop root pressure ?
   ✓ Every activity requires energy. Root pressure develops due to activity of living cells of the root.
8. Define guttation ?
   ✓ The loss or excretion of water in the form of liquid droplets from the leaves and other parts of an uninjured oor intact plant is called **guttation**.
9. What are hydathodes ?
   ✓ Special structures found on margins and tips of leaves made of epithem cells and water pores through which guttation takes place.
10. What is atmometer ?
    ✓ It is an apparatus for demonstrating and measuring pull caused by evaporation of water from a porous pot.
11. If in an osmotic system, one chamber has a Ψ of –1000 kPa while the other has –500 kPa, which chamber has higher Ψ and what is it ?
    ✓ Chamber with –500 kPa. It has dilute solution.
12. What would be Ψ_p of a flaccid cell ?
    ✓ Zero.
13. What would be Ψ_p of a plasmolysed cell ?
    ✓ Negative.
14. Which organisms other than plants possess cell wall ?
    ✓ Bacteria, fungi, some protists.
15. Where are porins present ?
    ✓ Outer membrane of Gram negative bacteria, mitochondria and plastids.
16. How many types of aquaporins recorded ?
    ✓ 8 types.

One Mark Questions (Without Answers)

1. Fill in the blanks :
   (a) The water potential of pure water is________
   (b) When plant absorbs the water from the soil, the water potential of the root cell is______than the soil.
   (c) Plants lose water by the process of______and______
   (d) Loss of the water through the epidermis of aerial parts of the plant is reduced by______
2. What are hydathodes ?
3. Which is the principal mineral cation in the extracellular fluid.
4. Name the pores through which guttation occurs.
5. Name the plant process carried by hydathodes.
6. Define osmosis.

7. A cell has OP of 10 bars and its TP is 6 bars, find its DPD ?
8. Who proposed K^+ hypothesis for opening and closing of stomata ?

Two Mark Questions (With sample Answers)

1. What is water potential ? Why is it negative in value ?
   ✓ It is difference in chemical potential per molal volume of water in a system and that of pure state at the same temperature and pressure. Water potential of pure water at normal temperature and pressure is zero. In solutions the value of water potential is always negative or less than zero.
2. A well watered potted herbaceous plant shows wilting in the afternoon of a dry sunny day. Why ?
   ✓ Wilting or loss of turgidity is quite common during noon due to transpiration being higher than the rate of water absorption.
3. When separated by a semipermeable membrane, water enters the sugar solution. What would you call the sugar solution — Osmotically active or inactive ?
   ✓ Osmotically active.
4. How root/shoot ratio affects transpiration ?
   ✓ A low root/shoot ratio decreases the rate of transpiration while a high ratio increases the rate of transpiration because of greater availability of water due to more extensive root system.
5. A plant is transpiring rapidly. Will it show root pressure also ?
   ✓ The rapidly transpiring plants do not show any root pressure. Instead a negative pressure is observed in most of the plants.
6. Trace the fate of molecule of water after it reaches the mesophyll cells.

Three Mark Questions (Short Answer Type)

1. What are guard cells ? Explain their role in regulating transpiration.
2. List the different factors that influence stomata.
3. Define hygroscopic and capillary waters ? Which is not available to plants and why ?
4. How do guard cells control opening and closing of stomata ?
5. How do Potassium ions regulate the opening and closing of stomata ?
6. List the three prominent theories to explain water translocation in trees. Describe the most accepted theory out of these.
7. Discuss the role of K^+ on the mechanism by which water moves into guard cells.
8. With the help of a labelled diagram describe briefly the closing and opening mechanism in stomata of plants such as common grass.
9. How do changes in TP help in opening and closing mechanism of stomata ?
10. Differentiate between TP and WP in plant cells. List any four ways in which turgidity serves a useful purpose in the plants.
11. Explain the significance of transpiration.
12. Differentiate between diffusion and osmosis.
13. Why do well watered plants transpire more during sunny and windy days than in cool and calm morning ? How transpiration is different from evaporation.

Five Mark Questions (Long Answer Type)

1. Discuss the importance of turgor pressure in life activities of plants.
2. Set up an experiment to demonstrate root pressure.
3. Write a note on hydathodes. Differentiate hydathodes from stomata.
4. What are the two kinds of interactions of water molecules that allow water to travel upward in plants? What other physical process aids in water transport to tops of trees ?
5. Explain why transpiration in higher plants is considered a necessary evil. *(HSB 2000, HSEB 2001)*
6. Define transpiration. Name the types of transpiration. Give the mechanism of transpiration giving V.S. of leaf.
7. How do potassium ions regulate the opening and closing of the stomata ?
8. Describe the active K^+ ion theory for stomatal opening.
9. What is ascent of sap ? Explain cohesion-tension theory for it.
10. What is transpiration ? Explain various factors affecting it.
11. Discuss role of transpiration pull in lifting water to the tops of tallest trees of the world.

Multiple Choice Questions (With Answers)

(1) Passive water absorption by root system is due to (a) force created in roots (b) osmotic force in shoot (c) high respiratory activity of root (d) tension in sap due to transpiration. *(KCET 2006)*

(2) Oozing of water drops from injured leaf edges is (a) bleeding (b) guttation (c) transpiration (d) oozation. *(Odisha 2006)*

(3) Accumulation of K^+ ions in guard cells shall cause (a) loss of turgidity (b) decrease in water potential (c) increase in water potential (d) exosmosis. *(Gujarat 2007)*

(4) **A and B** are contiguous cells. **A** has OP = 10 atm, TP = 7 atm and DPD = 3atm. **B** has OP = 8 atm, TP = 3 atm, DPD = 5 atm. The result would be (a) no movement of water (b) equilibrium between the two (c) movement of water from **A** to **B** (d) movement of water from **B** to **A**. *(CBSE 2007)*

(5) Opening of stomata is not affected by (a) N_2 (b) K^+ ions (c) Starch (d) None of the above. *(DPMT 2008)*

(6) Rupture and fractionation of water column present in tracheary elements does not occur during ascent of sap due to (a) transpiration pull (b) weak gravitational pull (c) cohesion and adhesion (d) lignified thick walls. *(CBSE 2008)*

(7) Water potential of pure water and its solution are (a) 0 and 1 (b) 0 and 0 (c) 0 and more than one (d) 0 and less than 1. *(Manipur 2009)*

(8) In walls of guard cells, cellulose microfibrils are arranged (a) obliquely (b) radially (c) transversely (d) taugentially. *(AMU 2009)*

(9) Solute potential of a solution is always (a) = 0 (b) < 0 (c) > 0 (d) between 0.1 to 1.0. *(DPMT 2010)*

(10) Loss of water from tip of leaves is called (a) Guttation (b) Transpiration (c) Evaporation (d) Respiration. *(MP PMT 2010)*

(11) Difference between osmotic pressure is (a) DPD (b) Osmotic potential (c) Solute potential (d) Transpiration pull. *(Wardha 2011)*

(12) Accumulation of which one of the following acids results in closure of stomata (a) Malic acid (b) Aspartic acid (c) PEP (d) OAA. *(AMU 2011)*

(13) Phloem sap is mainly (a) water and minerals (b) water and sucrose (c) oligosaccharides and hormones (d) none of the above. *(AMU 2012)*

(14) Guttation occurs through (a) stomata (b) lenticels (c) cuticle (d) hydathodes. *(Chd. CET 2012)*

(15) Osmotic potential of pure water is (a) Zero atm (b) 1 atm (c) 10 atm (d) 100 atm. *(MP PMT 2013; NEET 2017)*

(16) Which does not pertain to facilitated transport (a) high selectivity (b) transport saturation (c) uphill transport (d) requirement of special membrane. *(NEET 2013)*

(17) Osmotic concentration of a cell kept in water is chiefly regulated by
(a) vacuoles (b) plastids (c) ribosomes (d) mitochondria. *(CBSE 2014)*

(18) Apoplast is located (a) outside the plasma membrane (b) in the entire cytosol (c) on both sides of plasma membrane (d) in the plastidial content. *(WB 2015)*

(19) A column of water within xylem vessels of tall trees does not break under its weight because of (a) dissolved sugar in water (b) tensile strength of water (c) lignification of xylem vessels (d) positive root pressure. *(CBSE 2015)*

(20) A few drops of sap were collected by cutting across a plant stem by a suitable method. The sap was tested chemically. Which one of the following test results indicates that it is phloem sap ?
(a) Absence of sugar (b) Acidic (c) Alkaline (d) Low refractive index. *(NEET 2016)*

(21) Which of the following facilitates opening of stomatal aperture ? (a) Contraction of outer walls of guard cells (b) Decrease in turgidity of guard cells (c) Radial orientation of cellulose microfibrils in the cell wall of guard cells (d) Longitudinal orientation of cellulose microfibrils in the cell wall of guard cells. *(NEET 2017)*

Assertion and Reason Type Questions

1. **Assertion**. Cut stumps pull the water column upwardly.
Reason. Transpiring leaves show exudation of sap.
(A) (B) (C) (D)

2. **Assertion.** Stomata remain open during the day time.
Reason. Stomata help in exchange of gases. *(AIIMS 2001)*
(A) (B) (C) (D)

3. **Assertion.** In angiosperms, the conduction of water is more efficient because their xylem has vessels.
Reason. Conduction of water by vessel elements is an active process with energy supplied by xylem parenchyma rich in mitochondria. *(AIIMS 2006)*
(A) (B) (C) (D)
4. **Assertion.** Dried seeds of Pea are kept in tin, water is poured cver them upto upper level. A lid is put tight over it. Within an hour the lid is blown off.
Reason. Due to rapid cell division in Pea seeds. *(AIIMS 2007)*
(A) (B) (C) (D)
5. **Assertion.** Water entering a plant cell makes it turgid.
Reason. Entry of water into a cell develops wall pressure inside the cell. *(AIIMS 2011)*
(A) (B) (C) (D)
6. **Assertion.** Translocation of sugar from source to sink is defined as pressure flow hypothesis.
Reason. Translocation of solute is facilitated through living phloem sieve tube cells. *(AIIMS 2017)*
(A) (B) (C) (D)

ANSWERS

17. (a) — zero (b) — lower (c) (i) — Transpiration (ii) — guttation (d) Antitranspirants.

Multiple Choice Questions (With Answers)

(1) — d (2) —a (3) — b (4) —c (5) —a (6) —c (7) —d (8) —b (9) —b (10) —a (11) —a (12) —a (13) —b (14) —d (15) —a (16) —c (17) —a (18) —a (19) —b (20) —c (21) —c

Assertion and Reason Type Questions

(1) —B (2) —B (3) —C (4) —C (5) —C (6) —B

12 MINERAL NUTRITION

The sum total of processes by which a living organism receives and utilizes raw materials for building its structure and maintaining body functions is called **nutrition.** The chemical substance that works as a raw material for body building and maintaining its functions is termed as **nutrient.** A nutrient can be simple or complex organic molecule, or a mineral ion. The two are respectively called **organic nutrient** and **inorganic nutrient.** CO_2 is an inorganic nutrient for plants. Protein component of our diet is organic nutrient for human beings.

Mineral nutrition is the study of source, mode of absorption, distribution and metabolism of various inorganic substances or minerals by plants for their growth, development, structure, physiology and reproduction. The first study in inorganic or mineral nutrition was carried out by Van Helmont in 1648. He observed that in five years the soil lost 56.7 gm in nourishing a young seedling to form a small tree. However, he did not know the significance of his observation. Glauber and Mayhow (1656) got increased plant growth on the addition of salt peter (KNO_3) to the soil. Woodward (1699) was the first to propose that soil provides mineral ingredients for nourishing plants. De Saussure (1804) concluded that the mineral content of the plant is got from the soil. Liebig (1840) clearly depicted the essentiality of mineral nutrition. He gave the **law of minimum** which states that productivity of a soil depends upon the proportionate amount of deficient mineral. German botanist Julius Sachs (1860) demonstrated for the first time that plants can be reared from seedling state to mature state in nutrient solution even in the absence of soil.

Methods to Study the Mineral Requirements of Plants

Mineral requirements of plants is determined by culture experiment first developed by German botanist Julius von Sachs (1860). The technique is believed to have been initiated by Home (around 1750) and improved by Knop (1865). Culture experiments are hydroponic experiments in which plants are grown from seeds to maturity in a defined nutrient solution in complete absence of soil. The early nutrient solutions were based on mostly macronutrients as micronutrients usually accompanied them as contaminants. As the chemically pure salts became available, the importance of micronutrients became clear. The first complete prescription of all known mineral salts required for preparing culture solution was given by Arnon and Hoagland (1940). Iron is provided alongwith a chelating agent, Na–EDTA. Water used in preparing culture solution is twice distilled in glass containers. Salts are chemically pure. In culture experiments, a solution containing the various mineral elements is prepared. A solution having all the essential elements in proper proportion is called **normal** or balanced **nutrient solution**. The element of which deficiency symptoms are to be studied is made deficient in the solution (Table 12.1). Seedlings are reared either directly in such solutions (**solution** or **water culture**) or in earthen pots having sterilized sand (**sand culture**). For studying the effect of microelements, cotyledons or other organs containing reserve food are removed because they are rich source of microelements. In a typical solution culture technique, nutrient solution is placed in superior glass jars or polythene

bottles covered with black paper (to prevent growth of algae and reaction of roots to sunlight). The jars contain split covers or corks with holes for suspending seedling, a funnel for adding solution and a bent tube for aeration (Fig. 12.1). Regular aeration is required for proper growth and activities of roots. pH of solution is checked from time to time and correction made. Culture experiments are useful in knowing :

1. Essentiality of mineral nutrients.
2. Role of an essential element in body structure and protoplasmic constituents of the plants.
3. Role of an essential element in the physiology of plants.
4. Deficiency symptoms.
5. Toxicity due to excess of an element.
6. Interaction of different elements.
7. Role of a nonessential but functional element.

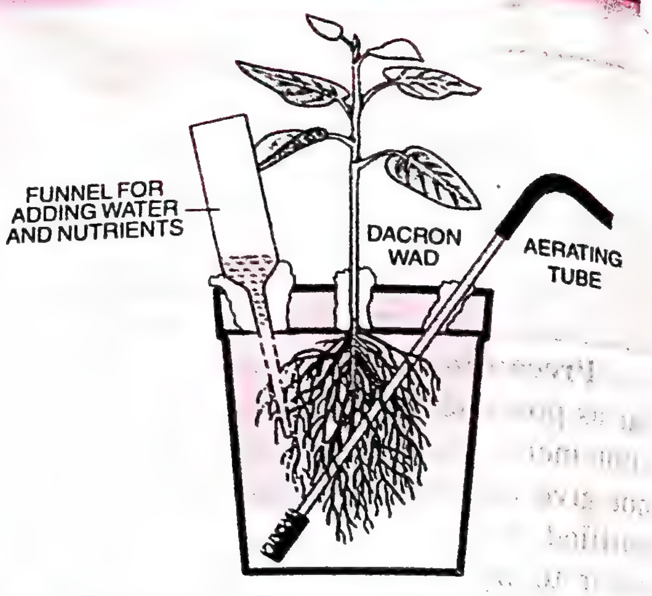


Fig. 12.1. Nutrient solution culture.

Table 12.1 Sach's Formulae for Solution Culture in 1 litre of distilled water (Sachs, 1860)

Constituents	*Normal*	*—P*	*—Ca*	*—K*	*—N*	*—Mg*	*—S*	*—Fe*
	gm	gm	gm	gm	gm	gm	gm	gm
KNO_3	0.70	0.70	0.70	—	—	0.70	0.70	0.70
$CaSO_4.2H_2O$	0.25	0.25	—	0.25	0.25	0.25	—	0.25
$Ca(H_2PO_4)_2.2H_2O$	0.25	—	—	0.25	0.25	0.25	0.25	0.25
$MgSO_4.7H_2O$	0.25	0.25	0.25	0.25	0.25	—	—	0.25
$NaCl$	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
$FeCl_3.6H_2O$	0.005	0.005	0.05	0.005	0.005	0.005	0.005	—
$Ca(NO_3)_2$	—	0.16	—	—	—	—	—	—
K_2SO_4	—	—	0.20	—	—	0.17	—	—
$Na_2HPO_4.12H_2O$	—	—	0.71	—	—	—	—	—
$NaNO_3$	—	—	—	0.59	—	—	—	—
KCl	—	—	—	—	0.52	—	—	—
$CaCl_2$	—	—	—	—	—	—	0.16	—
$MgCl_2$	—	—	—	—	—	—	0.21	—

Table 12.2 Knop's formula in grams for one litre of normal solution (Knop, 1865)

KNO_3	0.2	KH_2PO_4	0.2
$Ca(NO_3)_2$	0.8	$FePO_4$	0.1
$MgSO_47H_2O$	0.2		

Table 12.3. Arnon and Hoagland's (1940) complete nutrient solution

Chemical	*gm/litre*	*Chemical*	*mg/litre*
KNO_3	1.02	H_3BO_3	2.86
$Ca(NO_3)_2$	0.492	$MnCl_2.4H_2O$	1.81
$NH_4.H_2PO_4$	0.23	$CuSO_4.5H_2O$	0.08
$MgSO_4.7H_2O$	0.49	$ZnSO_4.7H_2O$	0.22
		$H_2MoO_4.H_2O$	0.09
$FeSO_4.7H_2O$(0.5%)	and	Tartaric Acid (0.4%)	0.6

Precautions. (1) Great care is taken to avoid contamination of the nutrient solution as far as possible, particularly with the trace elements which are often present as impurities in container's wall or water used in making nutrient solution or reagents being used. This does not give correct result about the essentiality of a mineral element. Due to this fact only purified water and mineral nutrients are used. (2) The containers are covered with black paper to prevent the growth of algae and phototropic reaction of roots to sunlight. (3) Adequate aeration of nutrient solution is essential to supply oxygen to roots to obtain optimum root growth and mineral uptake.

Hydroponics (Gericke, 1937; Fig. 12.1)

Solution culture is being used for raising flowers and vegetables at home. This soilless production of plants is called **hydroponics** (Gk. *hydor*— water, *ponas*— excretion). Plants are raised in small tanks of concrete or metal. The upper covering has supports for plants. The narrow tanks are provided with nutrient solution. A pump circulates air as well as nutrient solution. Roots of the plants are, therefore, regularly provided with aerated nutrient solution. Hydroponics is useful in areas having thin, infertile and dry soils. They conserve water. Additionally hydroponics can regulate pH optimum for a particular crop, control soil borne pathogens, avoid problems of weeding and obtain consistently better yield. Out of season vegetables (*e.g.*, Tomato, seedless Cucumber, Lettuce) and flowers can also be obtained. However, the cost of setting up a hydroponic system is very high.

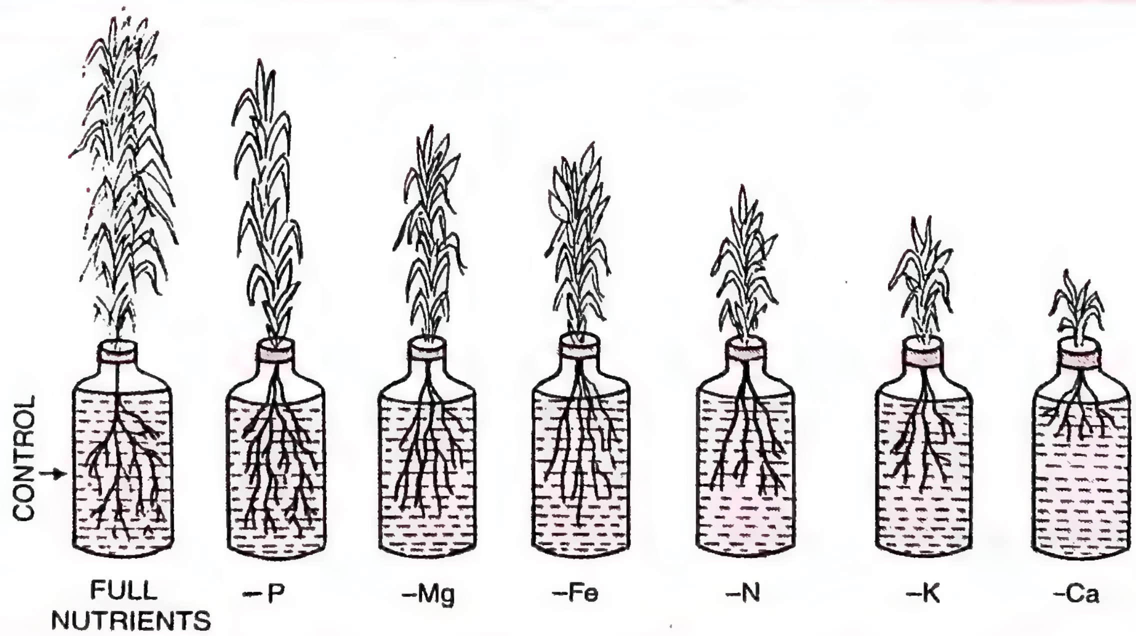


Fig. 12.2. Solution culture technique to know the essentiality of minerals.

Hydroponics are of four types— tank system, a film system, aeroponics and **ebb and flow hydroponics**. In tank system hydroponics (Gericke, 1937), the roots are immersed in nutrient solution and air is bubbled through the solution (Fig. 12.3 A). In film technique of hydroponics (Cooper, 1979), plants are grown in a trough or tube having a thin film of recirculated nutrient solution (Fig. 12.3 B). In aeroponics (Weathers and Zobel, 1992) roots are suspended in the air over the nutrient solution which is whipped into a nutrient mist (cloud of moisture in the air) by a motor driven rotor (Fig.12.3 C). The nutrient solution is periodically raised to moisten plant roots in ebb and flow system (Epstein and Bloom 2005).

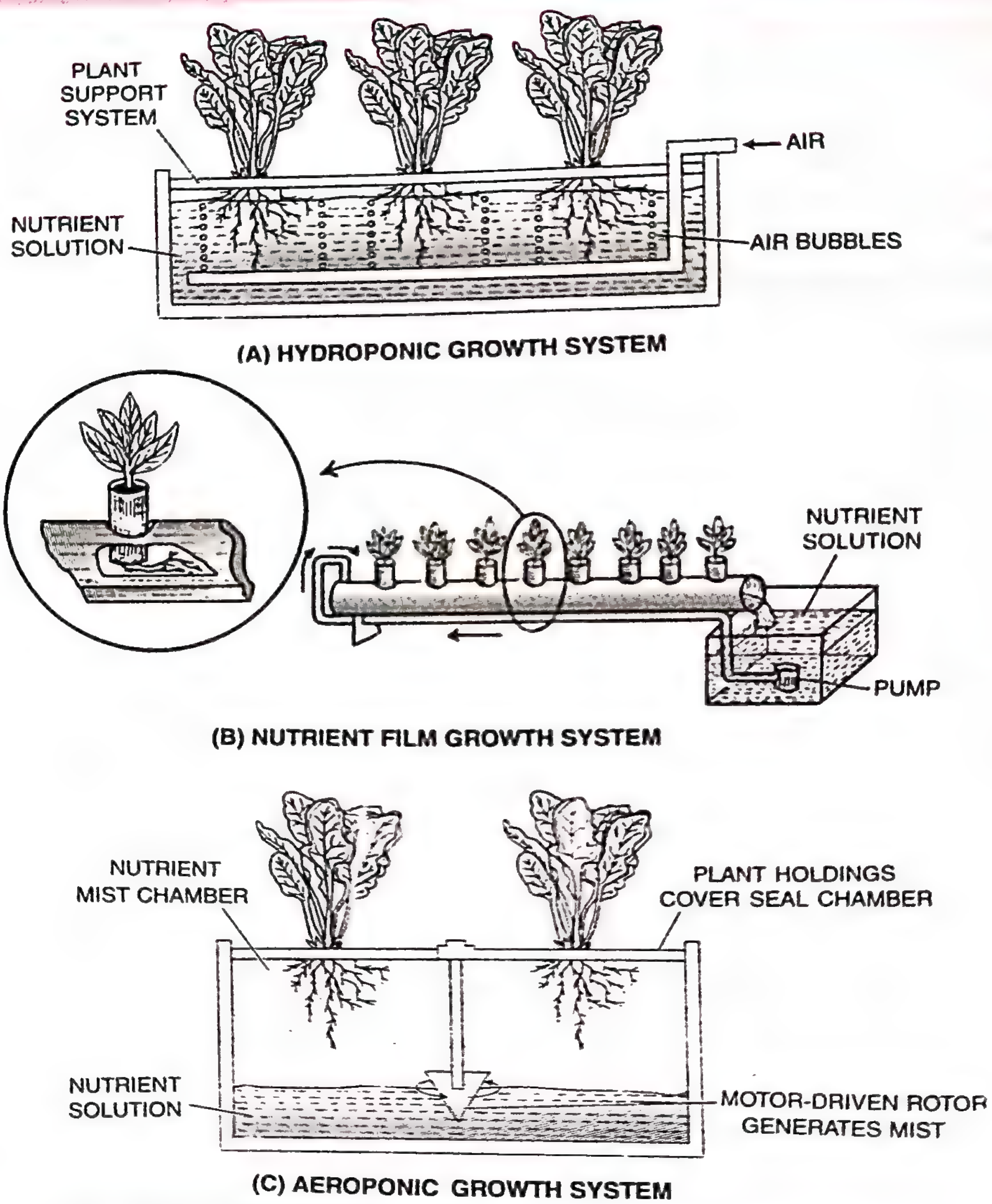


Fig. 12.3. Hydroponic and aeroponic systems for growing plants in nutrient solutions under controlled conditions.

Essential Mineral Elements

Most of the minerals present in the soil can enter plants. With the help of sensitive techniques, concentration as low as 10^{-8} g/ml can be detected. More than sixty minerals present in soil have been recorded in plants. Some plants accumulate heavy and toxic materials, *e.g.*, *Astragalus* (selenium), *Phacelia sericea* (gold), plants growing near nuclear

sites (radioactive strontium). All the elements found in plants are not essential for plants. Similarly, all elements essential for animal growth are not required by plants. The most important of them are iodine and sodium. An **essential element** is the one which has a specific structural or physiological role and without which plants cannot complete their life cycle.

Criteria to know essentiality of an element. Arnon and Stout (1939) proposed **criteria** for knowing the essentiality of an element. They are :

1. It is indispensable for the growth of plants.
2. The element is directly involved in the metabolism of plants. It becomes a component of either a structural or functional molecule. The element may additionally have a corrective effect on mineral balance and other soil conditions.
3. A plant is unable to complete its vegetative or reproductive phase in the absence of the element.
4. The element cannot be replaced by any other element.
5. The absence or deficiency of the element produces disorders. These disorders are a direct result of the lack or deficiency of the element.
6. The element alone can correct the disorders produced by its absence or deficiency.

17 elements have been found to be essential. They are C, H, O, N, P, K, S, Mg, Ca, Fe, B, Mn, Cu, Zn, Mo, Cl and Ni. Others are called **nonessential elements**. However, some of the nonessential elements have been found to be required in metabolic activities of certain plants. They include cobalt, silicon, sodium, vanadium, aluminium, etc. Silicon is required by most grasses and cereals. Its deficiency produces leaf necrosis and stunted growth in Rice (Yoshida *et al*, 1959). Sodium seems to be involved in membrane permeability though its essentiality has not been proved. These elements are called functional elements or **non-essential functional** or **beneficial elements.**

Macroelements and Microelements

Essential elements occur in different proportions (Table 12.1) in the plants. They are differentiated into two categories, macroelements and microelements. The terms major, minor and trace elements are generally rserved for elements involved in animal nutrition.

Table 12.4. Average concentration of various elements in plants
(as calculated on the basis of dry matter by Strout, 1961)

Macronutrient	*Concentration μg*	*Micronutrient*	*Concentration μg*
Carbon	450,000	Iron	100
Oxygen	450,000	Chlorine	100
Hydrogen	60,000	Manganese	50
Nitrogen	15,000	Boron	20
Potassium	10,000	Zinc	20
Calcium	5,000	Copper	6
Phosphorus	2,060	Nickel	3
Magnesium	2,000	Molybdenum	0.1
Sulphur	1,000		

(i) **Macroelements** (Macronutrients). They are those essential elements which are present in easily detectable quantities, in excess of 10m mole/kg or 1–10 mg per gram of dry matter. Macroelements are usually involved in the synthesis of organic molecules and

development of osmotic potential. They are nine in number— C, H, O, N, P, K, S, Mg and Ca. 96% of the dry matter is formed of carbon, hydrogen and oxygen. On **fresh weight basis**, oxygen is the most abundant element in plant body as well as other organisms. On **dry weight basis**, it is almost as abundant as carbon. Of the nonessential functional or beneficial elements, silicon and sodium often occur in the range of macroelements.

Iron occurs in the concentration of less than 1 mg/gm. However, its essentiality was discovered alongwith other macroelements long before microelements were found to be required. Therefore, it is often regarded to be macroelement.

(ii) **Microelements** (Micronutrients). They are those essential elements which are required by plants in small amounts, less than 10m mol/kg or 1.0 mg/gm of dry matter. Their essentiality came to be known only when extra pure salts were used in culture experiments. Microelements are mostly involved in the functioning of enzymes, as cofactors or metal activators. They are eight in number — Fe, Zn, Mn, B, Cu, Mo, Cl and Ni. Nonessential functional or beneficial elements which belong to the category of microelements are cobalt, vanadium and aluminium.

Differences between Macroelements and Microelements

Macroelements (Macronutrients)	*Microelements (Micronutrients)*
1. They occur in plants in easily detectable quantities.	1. They occur in plants in very small amounts.
2. The concentration of a macroelement per gm of dry matter is at least 1 mg or 1000 μg/gm of the dry matter.	2. The concentration of a microelement is equal to or less than 0.1 mg/gm of dry matter.
3. They build up the plant body and different protoplasmic constituents.	3. Microelements do not have such a role.
4. Some macroelements accumulate in cell sap and take part in developing osmotic potential.	4. Microelements, being found in traces only, have no significant role in the development of osmotic potential.
5. Turgor movements are mostly caused by influx & efflux of potassium, a macro-element.	5. None of the microelements have any such function.
6. They do not become toxic in slight excess.	6. Microelements are toxic in slight excess.

Mineral and Non-mineral Elements

Essential elements derived from soil are termed as **mineral elements**. Essential elements got from air or water are known as **nonmineral elements**, *e.g.*, C, H, O. They are building blocks of macromolecules that form the bulk of plant body. In aquatic habitats as well as in soil solution, mineral elements occur dissolved in water. Carbon is mostly got from air as CO_2. Hydrogen is obtained from water. Oxygen is a component of water. It is also available from air. Nitrogen is present in abundance in the air as a nonmineral element but plants usually obtain it from soil as nitrate or ammonium ion. The two are formed by the process of fixation of atmospheric nitrogen though a small quantity can also come from weathering of rocks. Chlorine is got as a mineral from soil but can also be obtained from the atmosphere. Similarly, some sulphur is also absorbed from the atmosphere where it is present as a pollutant in the gaseous state of sulphur dioxide.

Mineral Elements. P, K, S, Mg, Ca, Fe, Zn, Mn, B, Cu, Mo, Cl and N.

Non-Mineral Elements. C, O, H and N.

Role of Essential Elements and Deficiency Symptoms

Element	*Obtained as*	*Region of plant in which required*	*Constituent of*	*Major Functions*	*Deficiency Symptoms*
1. Nitrogen	NO_3^-, NH_4^- rarely NH_2^-	Everywhere but more in meristems	Amino acids, proteins, enzymes, some coenzymes, nucleotides, ATP nucleic acids,vitamins, hormones, cytochromes, chlorophyll.	Cell division, growth, metabolic activities, photosynthesis	Chlorosis starting from older leaves, stunted growth due to decreased protein synthesis, smaller cells and inhibition or slow divisions, permature leaf fall, lateral buds and tillering suppressed, late flowering, purple colouration of stem, petiole and under surface of leaf in some plants, wrinkling of cereal grains, reduced yield.
2. Phosphorus	$H_2PO_4^{2-}$, PO_4^{3-},	Meristems, developing fruits and seeds, withdrawn from older tissues. Stored as phytin or phytic acid.	Nucleotides, ATP nucleic acids, nucleoproteins, phospholipids, NAD^+, $NADP^+$ and some other coenzymes.	Energy transfer, cell division, membranes, phosphorylation reactions	Stunted growth, leaves dull green or with purple and red spots of anthocyanins, chlorosis (appears late) with necrosis first in older leaves or premature abscission, delayed flowering, premature fall of flower buds, poor vascular tissues and delayed seed germination.
3. Potassium	K^+	Leaves, meristems, buds and root tips.	Not constituent of any organic substance, cofactor or activator of several enzymes, determines osmotic potential	Maintenance of cell turgidity, opening and closing of stomata, balancing other ions, cation-anion balance, increases hardiness, essential for photosynthesis, respiration, protein synthesis and synthesis of various other types, membrane permeability.	Mottled interveinal chlorosis appearing first in older leaves, marginal or apical yellowing or scorch and curling, die back, bushy habit, shorter internodes, loss of apical dominance, cereals may show lodging, loss of cambial activity, plastid disintegration and increase in rate of respiration.
4. Calcium	Ca^{2+}	Meristematic and differentiating tissues. Excess in older leaves.	Calcium pectate of middle lamella, activator of enzymes connected with chromosome formation and many aspects of metabolism.	Selective permeability of cell membrane, organisation of mitotic spindle, meristematic activity, metabolism, prevention of mineral and organic acid toxicity, second messenger for some hormonal signals.	Stunted growth, degeneration of meristems, especially root apex, chlorosis, necrosis and curling appearing first in young leaves, premature flower abscission, blossom end rot of Tomato.

Element	Obtained as	Region of plant in which required	Constituent of	Major Functions	Deficiency Symptoms
5. Magnesium	Mg^{2+}	Leaves, growing areas of root and stem, seeds, withdrawn from ageing leaves.	Chlorophyll, magnesium pectate, activator of enzymes connected with phosphate transfer in respiration, photosynthesis, DNA and and RNA synthesis, fat and carbohydrate metabolism, binding of ribosomes.	Formation of chlorophylls, carotenoids and nucleic acids, growth, metabolism and nodule formation in legumes.	Marginal curling, interveinal chlorosis with purple anthocyanin pigmentation appearing first in older leaves, veins green, chlorotic areas may turn necrotic, premature leaf abscission, reduced growth, underdeveloped phloem and pith.
6. Sulphur	SO_4^{2-}, also as SO_2 from air	Young leaves and meristems, withdrawn from senescent organs.	Two amino acids (methionine and cysteine) and hence their proteins, vitamins (thiamine, biotin), CoA, lipoic acid and ferredoxin, also component of allyl oils of Onion, Garlic and Crucifers.	Chlorophyll formation, growth metabolism and nodule formation in legumes.	Similar to those of nitrogen deficiency both being consituents of proteins. Chlorosis more commonly appearing first in young leaves accumulation of anthocyanins, stunted growth, leaf curl, less juice content in Citrus, reduced nodulation in legumes, smaller chlorotic leaves in Tea (tea yellow).
7. Iron (Micro)	Fe^{3+} (mostly) Fe^{2+} (mostly acidic soils)	Everywhere, more along veins. Excess stored as ferritin.	Cytochromes, ferredoxin, nitrogenase, activator of catalase and some other enzymes.	Electron transport in photosynthesis and respiration ($Fe^{2+} \rightleftharpoons Fe^{3+}$), development of chloroplasts, chlorophyll and other pigments, protein synthesis.	Interveinal chlorosis appearing first in young leaves, veins initially green, necrosis later on, growth reduced.
8. Manganese (Micro)	Mn^{2+}	Leaves and seeds	Activates enzymes of respiration,photosynthesis and nitrogen meta-bolism performing oxidation, reduction, decarboxylation, component of oxygen evolving complex.	Metabolism and photolytic evolution of oxygen.	Interveinal chlorosis, grey specks and streaks, legume cotyledons with brownish spots (marsh spot disease), stunted growth, flowers often sterile.
9. Molybdenium (Micro)	$HMoO_4^-$ MoO_4^{2-}	Everywhere, Mo^{4+} more common in roots	Nitrogenase, nitrate reductase, activator of dehydrogenases.	Nitrogen metabolism (nitrogen fixation, nitrate reduction), ascorbic acid synthesis. Oxidation–	Mottled chlorosis with marginal necrosis and infolding, lamina or upper half of lamina falls down (whiptail

Element	Obtained as	Region of plant in which required	Constituent of	Major Functions	Deficiency Symptoms
				reduction reaction.	disease), loosening of inflorescence in Cauliflower, slight growth retardation.
10. Boron (Micro)	BO_3^- or $B_4O_7^{2-}$	Leaves and seeds	Connection with any enzyme system not known.	Carbohydrate transport through phloem, uptake and utilization of calcium, pollen germination, root nodulation, synthesis of pectins, proteins and nucleic acids, membrane functions, cell elongation and cell differentiation.	Death of root and shoot tips, loss of apical dominance, stunted growth, small size of fruits, rossetting of leaves, stem brittle but stout, black necrosis, disintegration of softer parts–top sickness, brown heart (*e.g.*, Turnip), internal cork (*e.g.*, Apple), heart rot of Sugar Beet, browning of Cauliflower, decreased nodulation in legumes.
11. Copper (Micro)	Cu^{2+}	Everywhere	Component or activator of plastocyanin, cytochrome oxidase, RuBP carboxylase and many other enzymes.	Electron transfer ($Cu^+ \rightleftharpoons Cu^{2+}$) maintenance of carbohydrate/nitrogen balance, chlorophyll synthesis.	Die back, skin splitting or exanthema, exuding gummy substance, apical necrosis of of young leaves extending towards base along the margins, (leaf tip disease = reclamation disease), blackening of Potato tubers.
12. Zinc (Micro)	Zn^{2+}	Enverywhere	Component or activator or several enzymes including carbonic anhydrase, dehydrogenases and carboxylases.	IAA, RNA and protein synthesis, evolution and utilization of carbon dioxide	Leaf malformations like little leaf, leaf rosettes, interveinal chlorosis and several types of leaf distortions, white bud, stunted growth.
13. Chlorine (Micro)	Cl^-	Everywhere	Component of oxygen liberation complex of photolysis, amylase, anion-cation balance, osmotic potential alongwith K^+, Na^+.	Photoproduction of oxygen, cell division, normal production of fruits.	Bronze colour in leaves, leaf wilting, chlorosis and necrosis, stunting of roots and swollen root tips, flower abscission, reduced fruiting.
14. Nickel (Micro)	Ni^{2+}	Leaves and root.	Urease, also required for hydrogenase.	Metabolism of urea and ureides.	Leaf tip necrosis.

Fig. 12.4. Potassium deficiency symptoms in Tomato leaf.

Fig. 12.5. Sugar Beet leaves showing calcium deficiency.

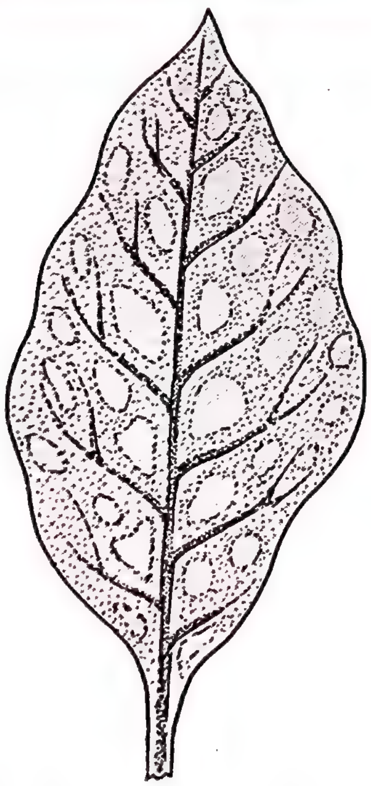


Fig. 12.6. Manganese deficiency pattern.

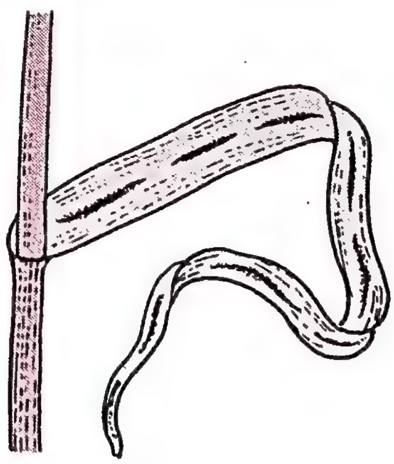


Fig. 12.7. Copper deficiency symptoms in cereal.

Fig. 12.8. Molybdenum deficiency symptoms.

General Role or Functions of Essential Elements

1. **Constituents of Biomolecules.** Carbon and hydrogen are components of all organic substances. Many of them also contain oxygen. Nitrogen is a constituent of all amino acids, proteins, nucleic acid, chlorophyll, auxin, cytokinins and vitamins. Sulphur occurs in two amino acids— methionine and cysteine. They form a number of proteins. Phosphorus is present in nucleotides, higher nucleotides (*e.g.*, ADP, ATP, CDP, CTP), coenzymes like NAD^+ and $NADP^+$, RNA, DNA and phospholipids. Fe is found in cytochromes. Mg is a component of chlorophyll. Ca and Mg produce pectates of middle lamella.

Depending upon the organic compound formed, mineral elements are of two types :

(a) **Frame-work Elements.** They produce cell walls and storage products of plants, *i.e.*, C, H, O.

(b) **Protoplasmic Elements.** The elements produce protoplasmic constituents like proteins, nucleic acids, chlorophylls, cytochromes, ferredoxin, *i.e.*, C, H, O, N, S, P, Mg, Fe.

2. **Energy Related Compounds.** Magnesium is a component of chlorophyll that takes part in conversion of light energy into chemical energy. Phosphorus is component of ATP which functions as energy currency of the living systems.

3. **Osmotic Potential.** Most of the osmotic potential of cell sap is due to inorganic salts. Osmotic potential is required for water absorption and maintenance of cell turgidity.

4. **Movements.** Free K^+ takes part in stomatal and other turgor movements.

5. **Buffer Action.** Weak acids and their salts function as a buffer against changes of *p*H.

6. **Oxidation Reduction System.** Metals with variable valency act as electron carriers, *e.g.*, Iron (Fe^{2+} and Fe^{3+}) and Copper (Cu^+, Cu^{2+}).

7. **Toxic Effects.** Many elements become toxic in higher concentration than the normal, *e.g.*, Cu, B, Mn, Mo, Zn. Others are toxic even in smaller concentration, *e.g.*, Pb, Ni, Se, Al, Hg.

8. **Balancing Elements.** Ca^{2+}, Mg^{2+} and K^+ minimise the toxic effect of heavy elements.

9. **Permeability.** Sodium, Potassium and some other monovalents increase membrane permeability while Calcium and other divalents decrease the same.

10. **Catalytic Effects.** Many enzymes require mineral elements as cofactors. Mg^{2+} is activator of several enzymes of both respiration (*e.g.*, hexokinase, phosphofructokinase) and photosynthesis (*e.g.*, RuBP carboxylase, PEP carboxylase). Zinc is activator of carbonic anhydrase and alcohol dehydrogenase. Molybdenum is required for functioning of dinitrogenase and nitrate reductase. Mn^{2+} is involved in photolysis of water. K^+ is known to be cofactor of some 40 enzymes.

11. **Phloem Transport.** Boron and Potassium are involved in the translocation of organic substances in the phloem.

Deficiency Symptoms of Essential Elements

Deficiency symptoms are externally visible pathological conditions (morphological and physiological deformities or abnormalities) *which are produced due to absence or deficiency of some essential nutritive substance.* Deficiency symptoms are also called **hunger signs.** They appear when the availability of the essential nutrients falls below the critical concentration. **Critical concentration** is that limited concentration of the essential element below

which growth of the plant is reduced. As each essential element has one or more specific structural and functional roles, its deficient supply results in appearance of abnormal signs called deficiency symptoms. The symptoms disappear when the deficient element is supplied. Deficiency symptoms appear first in young leaves and young tissues for elements which are relatively immobile inside the plant, *e.g.*, Ca, S. They appear first in old leaves and tissues for those elements which are mobilised from senescing regions for supply to young tissues. Knowledge of deficiency symptoms in relation to particular elements help the farmer and the farm scientist to recognise the same when they are present in a field or area. Immediate corrective measure can then be taken by supplying the missing or deficient nutrient to the soil or directly spraying it over the crop.

Deficiency symptoms are first studied by means of **pot** and **culture experiments**. Rapidly growing plants which develop characteristic symptoms are used in culture experiments. They are called **test (= indicator) plants**. They are then grown in soil under test in small pots. The results are compared to know the deficiency elements. Similar tests are performed with selected crops.

Excess of minerals are often toxic. The toxicity is studied first in culture experiments and then field or soil trials.

Common Deficiency Symptoms

(1) **Chlorosis.** Non-development or loss of chlorophyll. N, K, Mg, S, Fe, Mn, Zn, Mo. (2) **Stunted Growth.** N, K, Ca, S, Zn, B, Mo, Cl. (3) **Purple Colouration of Shoot Axis or Leaves.** N, P, Mg, S, Mo. (4) **Necrosis.** Death of tissues. Ca, Mg, Cu, K. (5) **Premature Fall of Leaves and Buds.** P, Mg, Cu. (6) **Inhibition of Cell Division.** N, K, S, Mo. (7) **Wrinkling of Cereal Grains.** N, S, Mo. (8) **Dormancy of Lateral Buds.** N, S, Mo. (9) **Late Flowering.** N, S, Mo. (10) **Die Back.** Killing of shoot apex (stem tip and young leaves). K, Cu. (11) **Wilting.** Loss of turgor. Cl. (12) **Death of Root and Shoot Tips.** B. (13) **Bushy Habit of Shoot.** K. (14) **Scorched Leaf Tips.** K. (15) **Interveinal Chlorosis.** Fe. (16) **Whiptail Disease of Leaves.** Mo.

Toxicity of Micronutrients

In higher doses, micronutrients become toxic. Any tissue concentration which reduces dry weight of tissue by 10% is called **toxic concentration.** Critical toxic concentration is different for different micronutrients as well as different plants. For example, Mn^{2+} is toxic beyond 600 µg g^{-1} for Soyabean and beyond 5300 µg g^{-1} for Sunflower. Toxic effects may be due to direct excess of the micronutrient or its interference in the absorption and functioning of other nutrients. Manganese toxicity (brown spots surrounded by chlorotic veins) is due to (i) Reduction in uptake of iron and magnesium. (ii) Inhibition of binding of Magnesium to specific enzymes. (iii) Inhibition of Calcium translocation into shoot apex. Therefore, excess of Manganese causes deficiency of Iron, Magnesium and Calcium. The toxicity symptoms of Mn are actually combined deficiency symptoms of Fe, Mg and Ca.

ABSORPTION OF MINERALS

Plants absorb their mineral salt supply from the soil through the roots. The most active areas of the root for mineral absorption are the zones of elongation and root hair. The rate of mineral absorption is usually independent of its concentration in the soil. The minerals are absorbed as ions. Ions are accumulated by the plants against their concentration in the soil. Isolated plant cells, tissues or organs placed in mineral solution, show two phases in mineral

absorption; initial and metabolic. In the **initial phase** there is a rapid uptake of ions into **outer** or **free space** of the cells. Outer or free space comprises intercellular spaces and cell walls. Ions absorbed in free space are freely exchangeable, *e.g.*, replacement of unlabelled K^+ ions with labelled K^+ ions. In the **metabolic phase** the ions pass into **inner space**. The latter comprises cytoplasm and vacuole. In the inner space the ions are not freely exchangeable with those of external medium. Entry of ions into outer space is **passive absorption** as no energy is required for it. Absorption of ions into inner space requires metabolic energy. It is, therefore, an **active absorption**. Movement of ions into cells is called **influx** while movement of ions out of the cells is called **efflux**.

Differences between Outer Space and Inner Space

Outer Space	*Inner Space*
1. It is area of apoplast.	1. It is area of symplast.
2. It is formed of intercellular spaces and cell walls.	2. It is formed of cell membranes, cytoplasm and other structures of living cells.
3. Ions move passively into outer space.	3. Ions move actively into inner space.
4. Ions occur in the outer space in freely exchangeable form.	4. There is no free exchange of ions.

TRANSLOCATION OF SOLUTES

After absorption from the soil by epiblema cells, the mineral salts pass radially inwards into the tracheary elements. With the transport of water the mineral salts also pass upwardly to reach the leaves and other parts. That xylem is the pathway for the transport of mineral salts is based on the following facts:

1. Xylem sap contains mineral salts.

2. Salt uptake increases with the increase in the rate of transpiration and transport of water.

3. Ringing and hollowing experiements which disrupt the continuity of cortex, phloem and pith do not influence the rate of mineral uptake till the roots are metabolically active.

4. **Tracer Technique.** Analysis of bark and wood shows that bark (including phloem) contains more minerals than the wood although phloem is not the pathway of transport of minerals. Therefore, Stout and Hoagland (1939) inserted a paraffin paper between xylem (wood) and phloem (bark) upto a length of 23 cm (Fig. 12.10). Radioactive potassium or phosphorous was added to the rooting medium. The concentration of radioactive mineral was found out at various levels in the stem near and in the area of separation of xylem and phloem (Table 12.5). The data shows that in the stripped area little concentration of mineral occurs in the bark though its amount is quite high in the xylem. Greater amount of mineral in the bark above and below the strip is due to local absorption of mineral from xylem by living cells of bark but there is little translocation through it. The pathway is only xylem.

Through xylem the absorbed minerals are passed into leaves. From leaves the mineral salts reach other parts through phloem.

Table 12.5. Concentration of radioactive K^+ after five hours when xylem and phloem are separated.

		Concentration Bark	ppm Wood
Above Strip	SA	53	47
	S_6	11.6	119
	S_5	0.9	122
Stripped Area	S_4	0.7	112
	S_3	<0.3	98
	S_2	>0.3	108
	S_1	20	113
Below strip	SB	84	48

Soil as Reservoir of Essential Elements

Soil provides anchorage, air, water and minerals to the plants growing in it. Soil colloids are particles that retain nutrients for release into the soil solution for uptake by roots. Thus, soil colloids maintain reservoir of soluble nutrients in the soil. Clay part of the soil and humus forms colloidal particles in the soil. The colloids carry a large number of charges on their surface as well as they have large surface area, for interaction with mineral elements in the soil. The charged surfaces bind large number of ions especially positively charged cations from the soil solution. This is most important property of soil. Soil also has a large number of microorganisms that not only decompose organic remains but also release the minerals bound in organic matter. Nitrogen fixing bacteria increase the usable nitrogen content of soil. Soil is able to maintain a regular supply of minerals partly by the activity of decomposers and partly by slow breakdown and weathering of rocks. This also replenishes the natural slow erosion of the top layers of soil. However, agriculture is slightly different from natural vegetation. There is more withdrawal of mineral nutrients from soil than their natural replenishment. Therefore, there is often deficiency of essential minerals. Artificial fertilizers are added to remove the same.

Fig. 12.9. Experiment to show path of mineral translocation as used by Stout and Hoagland (1939).

NITROGEN NUTRITION OR METABOLISM OF NITROGEN

Nitrogen Cycle (Fig. 12.10). Nitrogen is the fourth most prevalent element in living systems. It is a constituent of a number of organic compounds like amino acids, proteins, nucleotides, nucleic acid, hormones, chlorophyll, many vitamins, etc. However, its availability from soil is limited and even for that plants have to compete with microbes both in natural and agricultural ecosystems. Nitrogen is available in the atmosphere in abundance (78% of atmosphere as dinitrogen or N_2) but plants cannot directly absorb the same. Therefore, nitrogen is the **most critical element**. A regular supply of nitrogen to the plants is maintained

through nitrogen cycle. **Nitrogen cycle** is regular circulation of nitrogen amongst living organisms, reservoir pool in the atmosphere and cycling pool in the lithosphere. Nitrogen compounds are obtained from reservoir pool through nitrogen fixation. Reservoir pool is replenished through denitrification of nitrates and release of nitrogen from decaying organic matter. Cycling pool is augmented by ammonification and nitrification. Plants obtain nitrogen from soil as NO_3^- (nitrate), NH_4^+ (ammonium) and NO_2^- (nitrite) ions. Nitrate and nitrite are reduced to ammonium state which is then incorporated into amino acids, proteins and other organic substances.

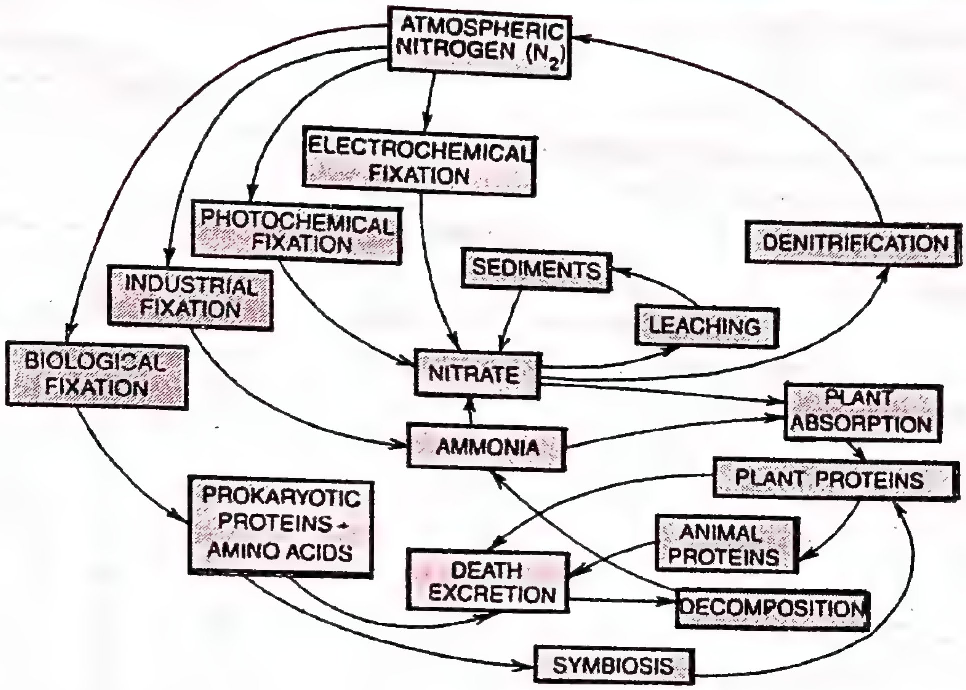


Fig. 12.10. Nitrogen cycle.

Nitrogen Fixation. It is the conversion of inert atmospheric nitrogen or dinitrogen (N_2) into utilisable compounds of nitrogen like nitrate, ammonia, amino acids, etc. There are two methods of nitrogen fixation— abiological and biological. Abiological nitrogen fixation is further of two kinds, natural and industrial.

Natural Abiological Nitrogen Fixation. Atmospheric nitrogen combines with oxygen in the presence of electric discharges, ozonization and combustion. Different types of nitrogen oxides are produced. The nitrogen oxides dissolve in water and give rise to hyponitrous, nitrous and nitric acids. They enter soil alongwith rain water forming hyponitrites, nitrites and nitrates.

$$N_2 + O_2 \xrightarrow[\text{Discharges}]{\text{Electric}} \underset{\text{Nitrogen oxide}}{2NO}$$

$$2NO + 2[O] \xrightarrow[\text{Ozonization}]{\text{Electric Discharges}} \underset{\text{Nitrogen peroxide}}{2NO_2}$$

$$2NO + 3[O] \xrightarrow{\text{Ozonisation}} N_2O_5$$

$$H_2O + 2NO \longrightarrow HNO + HNO_2$$
$$H_2O + 2NO_2 \longrightarrow HNO_2 + HNO_3$$
$$H_2O + N_2O_5 \longrightarrow 2HNO_3$$

Industrial Abiological Nitrogen Fixation. Ammonia is produced industrially by direct combination of nitrogen with hydrogen (got from water) at high temperature and pressure. It is changed to various types of fertilizers including urea.

Biological Nitrogen Fixation. It is the second most important natural process and the major source of nitrogen fixation which is performed by two types of prokaryotes, bacteria and cyanobacteria (= blue green algae). They include both free living and symbiotic forms.

(a) **Free Living Nitrogen Fixing Bacteria.** *Azotobacter, Beijerinckia* (both aerobic) and *Bacillus, Klebsiella, Clostridium* (all anaerobic) are saprotrophic bacteria that perform nitrogen fixation. *Desulphovibrio* is chemotrophic nitrogen fixing bacterium. *Rhodopseudomonas, Rhodospirillum* and *Chromatium* are nitrogen fixing anaerobic photoautotrophic bacteria. Free living nitrogen fixing bacteria add 10–25 kg of nitrogen/ha/annum.

(b) **Free Living Nitrogen Fixing Cyanobacteria.** Many free living blue- green algae (BGA) or cyanobacteria perform nitrogen fixation, *e.g., Anabaena, Nostoc, Calothrix, Lyngbia, Aulosira, Cylindrospermum, Trichodesmium.* They add 20–30 kg of nitrogen per hectare of soil and water bodies. Cyanobacteria are also important ecologically as they occur in water-logged soils where denitrifying bacteria can be active. *Aulosira fertilissima* is the most active nitrogen fixer in Rice fields while *Cylindrospermum* is active in Sugarcane and Maize fields.

(c) **Symbiotic Nitrogen Fixing Cyanobacteria.** *Anabaena* and *Nostoc* species are common symbionts in lichens, *Anthoceros, Azolla* and Cycad roots. *Azolla pinnata* (a water fern) has *Anabaena azollae* in its fronds. It is often inoculated to Rice fields for nitrogen fixation.

(d) **Symbiotic Nitrogen Fixing Bacteria.** *Rhizobium* is nitrogen fixing bacterial symbiont of papilionaceous roots. *Sesbania rostrata* has *Rhizobium* in root nodules and *Aerorhizobium* in stem nodules. *Frankia* is symbiont in root nodules of several nonlegume plants like *Casuarina* (Australian Pine), *Myrica* and *Alnus* (Alder). *Xanthomonas* and *Mycobacterium* form symbiotic association with the leaves of several members of rubiaceae and myrsinaceae (*e.g., Ardisia*).

Rhizobium lives free as aerobe in the soil but is unable to fix nitrogen. It develops the ability to fix nitrogen only as a symbiont when it becomes anaerobic. *Rhizobium* is rod-shaped bacterium *Frankia*, an actinomycete, can fix nitrogen both in the free and symbiotic state. It is aerobe and uses hopanoids as oxygen scavenger for providing anaerobic conditions to its nitrogenase (Kniep 2007). It is the most important for crop lands because it is associated with pulses and other legumes of family fabaceae, *e.g.,* Chick Pea or Gram (*Cicer arietinum*), Pigeon Pea or Red Gram (*Cajanus cajan*), Garden or Edible Pea (*Pisum sativum*). Soya bean (*Glycine max*), Lentil (*Lens culinaris*), Green Gram (*Vigna radiata = Phaseolus aureus*), Black Gram (*Vigna* or *Phaseolus mungo*), Sweet Clover, Sweet Pea, Alfalfa, Broad Bean, Clover Bean. Several species of the bacterium (*e.g., Rhizobium leguminosarum, R. meliloti*) live in the soil. They are unable to fix nitrogen by themselves. Roots of a legume secrete chemical attractants (flavonoids and betaines). Bacteria collect over the root hairs, release *nod* factors that cause curling of root hairs around the bacteria, degradation of cell wall and formation of an **infection thread** enclosing the bacteria (Fig. 12.11). Infection thread grows alongwith multiplication of bacteria. It branches and its ends come to lie opposite protoxylem points of vascular strand. The infected cortical cells dedifferentiate and start dividing. It produces swellings or nodules. Nodule formation is stimulated by **auxin** produced by cortical cells and **cytokinin** liberated by invading bacteria. The infected cells enlarge.

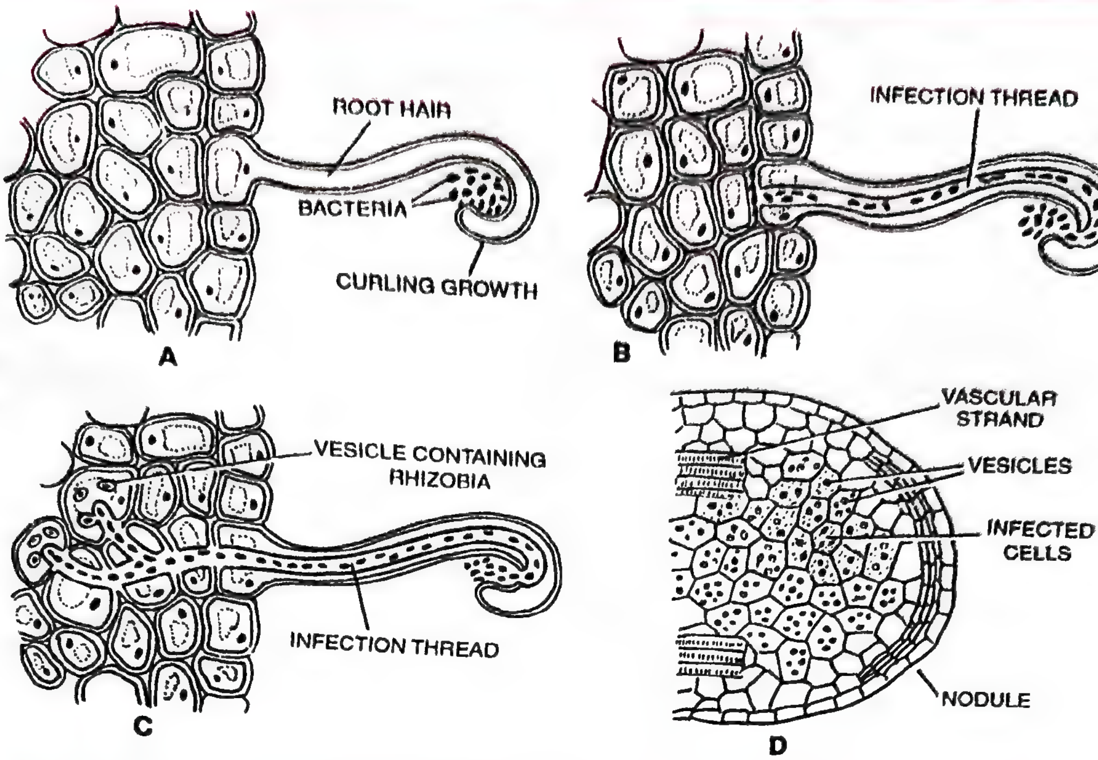


Fig. 12.11. Nodule formation in the root of a legume.

Bacteria stop dividing and form irregular polyhedral structures called bacteriods (Fig. 12.12). However, some bacteria retain normal structure, divide and invade new areas. In an infected cell bacteriods occur in groups surrounded by host membrane. The host cell develops a pinkish pigment called **leghaemoglobin (Lb)**. Leghaemoglobin has ten times more affinity for oxygen as compared to blood pigment haemoglobin. Leghaemoglobin acts as oxygen scavenger. It protects nitrogen fixing enzyme nitrogenase from oxygen. Symbiotic nitrogen fixation requires cooperation of *Nod* genes of legume, *nod, nif* and *fix* gene clusters of bacteria.

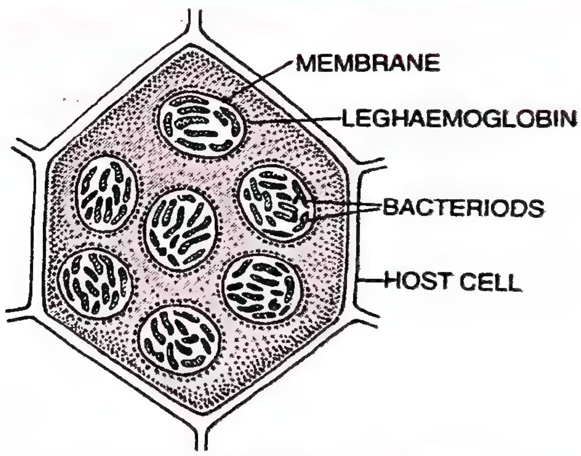


Fig. 12.12. Bacteriods in a nodule.

Mechanism of Nitrogen Fixation. Nitrogen fixation requires (i) a reducing power like NADPH, $FMNH_2$ (ii) a source of energy like ATP (iii) enzyme dinitrogenase and (iv) compounds for trapping ammonia formed by the reduction of dinitrogen. Enzyme nitrogenase has iron and molybdenum. Both of them take part in attachment of a molecule of nitrogen (N_2). Bonds between the two atoms of nitrogen become weakened by their attachment to the metallic components. The weakened molecule of nitrogen is acted upon by hydrogen (Fig. 12.13) from a reduced coenzyme. It produces **dimide** (N_2H_2), **hydrazine** (N_2H_4) and then **ammonia** ($2NH_3$). Ammonia is not liberated. It is toxic in even small quantities. The nitrogen fixers protect themselves from it by providing organic acids. The reaction between ammonia and organic acids gives rise to amino acids.

$$N_2 + 8e^- + 8H^+ + 16\,ATP \xrightarrow{\text{dinitrogenase}} 2NH_3 + 2H^+ + 16\,ADP + 16\,Pi$$

$$\text{Ammonia} + \alpha\text{-ketoglutarate} + NAD(P)H \xrightarrow{\text{dehydrogenase}} \text{Glutamate} + NAD(P)^+ + H_2O$$

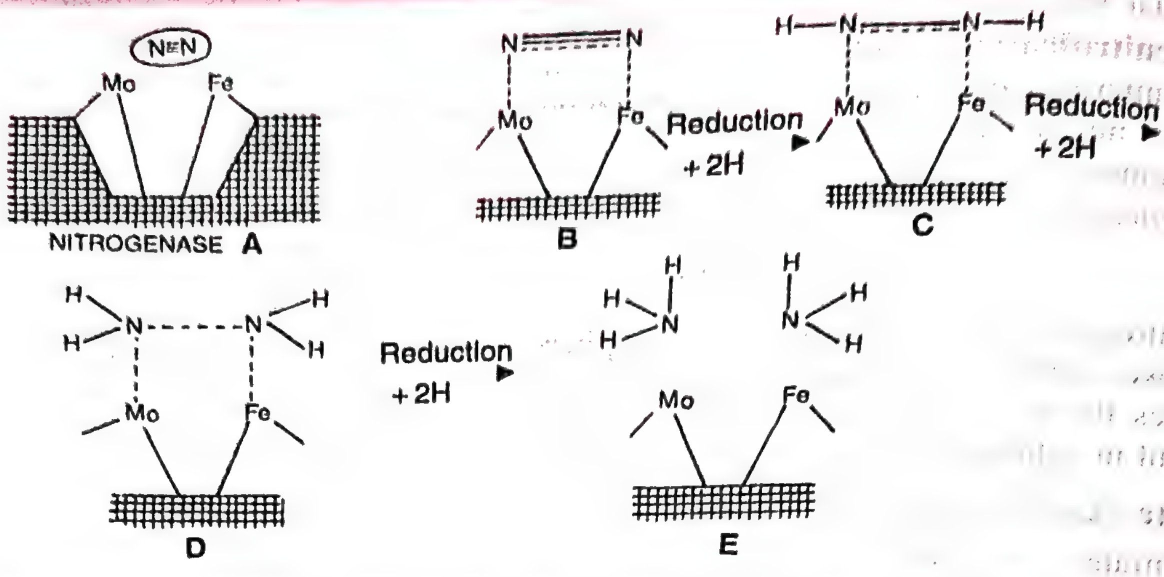


Fig. 12.13. A, structure of nitrogenase; B-E, Weakening of nitrogen bonds and addition of hydrogen to nitrogen with the help of Mo and Fe atoms.

Symbiotic nitrogen fixing organisms hand over a part of their fixed nitrogen to the host in return for shelter and food. Free living nitrogen fixers do not immediately enrich the soil. It is only after their death that the fixed nitrogen enters the cycling pool. It occurs in two steps, **ammonification** and **nitrification**.

Ammonification. It is carried out by decay causing organisms. They act upon nitrogenous excretions and proteins of dead bodies of living organisms, *e.g., Bacillus ramosus, B. vulgaris, B. mesentericus, Actinomyces*. Proteins are first broken up into amino acids. The latter are deaminated. Organic acids released in the process are used by microorganisms for their own metabolism.

$$\text{Proteins} \xrightarrow{+H_2O} \underset{\text{Amino acid}}{R-NH_2} \xrightarrow{H_2O} \underset{\text{Organic acid}}{ROH} + \underset{\text{Ammonia}}{NH_3}$$

Ammonia does not remain in the gaseous state in the soil but is changed to ionic form (NH_4^+). It can be used by plants directly provided *p*H of soil is more than 6 and the plant contains abundant organic acids. Unlike nitrates, very few plants can store ammonium ions (*e.g., Begonia, Oxalis*).

Nitrification. It is the phenomenon of conversion of ammonium nitrogen to nitrate nitrogen. It is performed in two steps— nitrite formation and nitrate formation. Both the steps can be carried out by *Aspergillus flavus*. In the first step, ammonium ions are oxidised to nitrites *Nitrosococcus, Nitrosomonas*. Nitrites are changed to nitrates in the second step, *e.g., Nitrocystis, Nitrobacter*.

$$2NH_3 + 3O_2 \xrightarrow[\textit{Aspergillus flavus}]{\textit{Nitrosococcus, Nitrosomonas}} 2\,NO_2^- + 2H^+ + 2H_2O + \text{energy}$$

$$2NO_2^- + O_2 \xrightarrow[\text{Aspergillus flavus, Nitrocystis}]{\text{Nitrobacter, Penicillium}} 2\,NO_3^- + \text{energy}$$

Most of the bacteria performing nitrification (*e.g., Nitrosococcus, Nitrosomonas, Nitrobacter*) are **chemoautotrophs**. They use the energy liberated during nitrification in synthesis of organic substances from CO_2 and a hydrogen donor. They are thus autotrophs which do not use solar energy for synthesis of food.

Denitrification. Under anaerobic conditions (*e.g.,* water logging, oxygen depletion), some microorganisms use nitrate and other oxidised ions as source of oxygen. In the process, nitrates are reduced to gaseous compounds of nitrogen. The latter escape from the soil. Common bacteria causing denitrification of soil are *Pseudomonas denitrificans, Thiobacillus denitrificans, Micrococcus denitrificans.*

$$2\,NO_3' \longrightarrow 2\,NO_2' \longrightarrow 2NO \longrightarrow N_2O \longrightarrow N_2$$

Nitrogen oxides escaping into atmosphere or formed during abiological fixation can also be broken down by raidations to form molecular nitrogen. Denitrification of soil not only depletes the soil of an important nutrient but also causes acidification which is equally harmful in solubilisation of harmful metals.

Nitrate Assimilation

Nitrate is the most important source of nitrogen to the plants. It can accumulate in the cell sap of several plants and take part in producing osmotic potential. However it cannot be used as such by the plants. It is first reduced to level of ammonia before being incorporated into organic compounds. Reduction of nitrate occurs in two steps :

(i) **Reduction of Nitrate to Nitrite.** It is carried out by the agency of an inducible enzyme called **nitrate reductase.** The enzyme is a molybdoflavoprotein. It requires a reduced coenzyme (NADH or NADPH) for its activity. The reduced coenzyme is brought in contact with nitrate by FAD or FMN.

$$NO_3 + NAD(P)H + H^+ \xrightarrow[\text{FAD/FMN}]{\text{Nitrate Reductase}} NO_2^- + H_2O + NADP^+$$

(ii) **Reduction of Nitrite.** It is performed by enzyme **nitrite reductase.** The enzyme is a metalloflavoprotein which contains copper and iron. It occurs inside chloroplasts in the leaf cells and leucoplasts of other cells. In contrast nitrate reductase is found attached loosely to cell membrane (Butz and Jackson, 1977). Nitrite reductase requires reducing power. It is NADPH in illuminated cells and NADH in others. The process of reduction also requires **ferredoxin** which occurs in higher plants mostly in green tissues. Therefore, it is presumed that in higher plants either nitrite is translocated to leaf cells or some other electron donor (like FAD) operates in unilluminated cells. The product of nitrite reduction is ammonia.

$$2\,NO_2^- + 7NAD(P)H + 7H^+ \xrightarrow[\text{Ferredoxin}]{\text{Nitrite reductase}} 2NH_3 + 4H_2O + 7NAD(P)^+$$

Ammonia is not liberated. It combines with some organic acids to produce amino acids. Amino acids then form various types of nitrogenous compounds.

Synthesis of Amino Acids

The first organic compounds of nitrogen assimilation are amino acids. They are synthesised by following three methods.

1. **Reductive Amination.** In the presence of dehydrogenase (*e.g.*, Glutamate dehydrogenase. Aspartate dehydrogenase), a reduced coenzyme (NADH or NADPH), ammonia can directly combine with a keto organic acid like α–ketoglutaric acid and oxaloacetic acid to form amino acid.

$$\alpha\text{–ketoglutaric acid} + NH_4^+ + NAD\,(P)H \xrightarrow[\text{dehydrogenase}]{\text{glutamate}} \text{Glutamate} + H_2O + NAD\,(P)$$

$$\text{Oxaloacetic acid} + NH_4^+ + NAD(P)H \xrightarrow[\text{dehydrogenase}]{\text{aspartate}} \text{Aspartate} + H_2O + NAD\,(P)$$

2. **Catalytic Amidation.** Ammonia combines with catalytic amounts of glutamic acid in the presence of ATP and enzyme glutamine synthetase. It produces an amide called glutamine. Glutamine reacts with α–ketoglutaric acid in the presence of enzyme glutamate synthetase to form two molecules of glutamate. Reduced co-enzyme (NADH or NADPH) is required.

$$\text{Glutamate} + NH_4^+ + ATP \xrightarrow[\text{synthetase}]{\text{glutamine}} \text{Glutamine} + ADP + Pi$$

$$\text{Glutamine} + \alpha\text{–ketoglutaric acid} + NAD\,(P)\,H \xrightarrow[\text{synthetase}]{\text{glutamate}} 2\,\text{Glutamate} + NAD\,(P)$$

3. **Transamination.** It is transfer of amino group (> CH NH_2) of one amino acid with the keto group (> C = O) of keto acid. The enzyme required is transaminase or aminotransferase. Glutamic acid is the primary amino acid involved in transfer of amino group (to as many as seventeen amino acids).

$$\text{Glutamic acid} + \text{Oxaloacetic acid} \xrightarrow[\text{Aminotransferase}]{\text{Glutamate aspartate}} \alpha\text{–ketoglutaric acid} + \text{Aspartic acid}$$

Amides

They are amino acid derivatives in which – OH component of carboxylic group (–COOH) is replaced by another amino group (– NH_2). Amides are, therefore, double aminated keto acids. The two most common amides are glutamine and asparagine. They are formed by amidation of glutamic acid and aspartic acid respectively. Another common amide is vitamin niacinamide (niacin *a*). Glutamine and asparagine are components of proteins alongwith amino acids. Their formation requires ATP, ammonia and synthetase enzyme (glutamine synthetase, asparagine synthetase). Amides perform two other functions— storage of excess nitrogen and transport. Transport generally occurs via xylem. *Ureides* (degraded urea) are employed as a means of nitrogen transport from the nodules of some legumes (*e.g.*, Soyabean) and retransport from the ageing organs. They have a high nitrogen to carbon ratio.

Protein Synthesis

It occurs through formation of amino acid chains or polypeptides over ribosomes through an elaborate process of translation of genetic code carried by mRNAs. Chain formation occurs through establishment of peptide bonds (–CONH–) between carboxylic group of one

amino acid and amino group of an adjacent amino acid. The arrangement of amino acid residues in a polypeptide chain is specific as per instructions or codons contained in mRNA. As a result each type of polypeptide has its own specific arrangement. Polypeptides give rise to proteins. Therefore, proteins are also highly specific.

ADDITIONAL INFORMATION

- **Liebig.** Father of Biochemistry who recorded minerals in plant ash and proposed the law of minimum.
- **Gericke.** Developed hydroponics.
- **Aeroponics.** It is the technique of growing plants in above-ground strands provided with fine mist of normal solution.
- **Neher and Sakmann.** Got Nobel prize for discovering single ion channels in the plasma membrane.
- **Most Free Ion.** Potassium.
- **Primary Deficiency.** Deficiency caused by a critical element (N, P or K).
- **Winogradsky** (1891). Discovered biological nitrogen fixation.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. All elements that are present in a plant need not be essential to its survival. Comment.

   ✓ Almost all elements which are present in soil and which get solubilised enter the plants. Nearly 60 elements have been detected in plants. However, all of them are not essential. Many of them simply enter the plants because of the common pathway with the essential elements, *e.g.*, lead, gold, selenium.

2. Why is purification of water and nutrient salts so important in studies involving mineral nutrition using hydroponics.

   ✓ Some minerals are required in extremely small quantity of even less than 1 μg /g of dry matter. Such small quantities are often present in water as well as in commercially available salts. Therefore, exact physiological role and deficiency symptoms of some elements cannot be studied unless and until extra pure water and extra pure salts are not used in studies employing hydroponics.

3. Explain with examples : (i) Macronutrients, (ii) Micronutrients, (iii) Beneficial nutrients, (iv) Toxic elements, (v) Essential elements.

   ✓ **Macronutrients.** They are those essential elements which occur in easily detectable quantities of 1–10 mg/g of dry matter, *e.g.*, C, H, O, N, P, K, S, Mg, Ca.

   Micronutrients. Micronutrients are essential elements found in plants in small quantities of 0.1 mg or less/g of dry matter, *e.g.*, Fe, Zn, Mn, B, Cu, Mo, Cl, Ni.

   Beneficial Nutrients. Nonessential elements which are required in metabolic activities of some plants are called **nonessential functional** or **beneficial elements**, *e.g.*, silicon in grasses, cobalt, vanadium, sodium.

   Toxic Elements. The elements which when present reduce growth of plants by 10% or more are known as toxic elements, *e.g.*, Lead, Aluminium. Most micronutrient also become toxic in higher concentration, *e.g.*, Mn^{2+}.

   Essential Elements. They are elements which have specific structural or functional roles in plants and without which plants are unable to complete their life cycle. Their deficiency produces disorders which can be corrected only by their supply, *e.g.*, C, H, O, N, P, K, S, Mg, Ca, Fe, Zn, Mn, etc.

4. Name atleast five different deficiency symptoms in plants. Describe them and correlate them with the concerned mineral deficiency.

   ✓ (i) **Interveinal Chlorosis.** Appearing first in young leaves, veins initially green ________ Iron.
   (ii) **Scorched Leaf Tips.** Potassium.
   (iii) **Whiptail Disease.** Molybdenum.
   (iv) **Exanthema** (skin splitting and exudation of gummy matter). Copper.
   (v) **Death of both Root and Shoot Tips.** Boron (also disintegration of softer regions).

5. If a plant shows a symptom which could be due to deficiency of more than one nutrient, how would you find out experimentally the real deficient mineral element ?

✓ Dilute solutions of all the possible deficient nutrients are prepared. A number of plants are grown in small pots using the nutrients deficient soil. Dilute solutions of different nutrients are added in different pots. In one set the growth of plants will become normal. The nutrient supplied to these plants had been deficient.

6. Why is that in certain plants deficiency symptoms appear first in younger parts of the plant while in others they do so in mature organs ?

✓ Deficiency symptoms appear first in the young parts for elements which are relatively immobile inside the plant, *e.g.*, Ca, S. They appear first in mature organs for those elements which are mobilised from senescing regions for supply to younger regions, *e.g.*, N, P, K, Ni.

7. How are the mineral elements absorbed by the plants ?

✓ Minerals are absorbed by cells of the root apex, zone of elongation and root hairs. Minerals absorbed by root hair zone are meant for passage to shoot while the ones absorbed by root apex and zone of elongation remain in the root.

Mineral absorption is an **active process.** It has two phases, initial phase and metabolic phase. Initial phase is a passive process where in ions absorbed from outside pass in outer or free space of the cells. It comprises intercellular spaces and cell walls. The **metabolic phase** is an active process wherein ions enter the cytoplasm and cell vacuole. Entry of ions into cells is called **influx.**

8. What are the conditions necessary for fixation of atmospheric nitrogen by *Rhizobium* ? What is their role in N_2 fixation.

✓ **Conditions.** (i) Reducing environment. (ii) Presence of enzyme nitrogenase. (iii) Source of energy as ATP. (iv) Source of reducing power, NAD (P) H_2 or $FMNH_2$. (v) Ferredoxin as electron donor. (vi) Ketoacids for picking up amino group. (vii) Reduced availability of nitrate in the substrate.

Role. (i) Enzyme nitrogenase is sensitive to presence of free oxygen. Therefore, a reducing environment is required. (ii) Enzyme nitrogenase helps in converting dinitrogen (N_2) to ammonia (NH_3). (iii) Reducing power or hydrogen is provided by NAD (P) H_2 or $FADH_2$. (iv) Ferredoxin makes nitrogen reactive. (v) Organic acids are required for formation of amino acids. (vi) Nitrate inhibits nitrogen fixation. Therefore, nitrate deficiency is prerequisite for nitrogen fixation.

9. What are the steps involved in formation of a root nodule ?

✓ Legume roots secrete flavonoids and betaines. They attract rhizobia. The bacteria collect over the root hairs and release *nod* factors. *Nod* factors cause curling of root hairs around the bacteria. Root hair wall degrades in the region. An infection thread containing the bacteria grows into root hair and then into the interior of root. Bacteria multiply in the infection thread. The infection thread branches. The branches reach and enter cortical cells opposite the protoxylem points. The infected cells dedifferentiate and start dividing. The stimulus is provided by auxin formed by cortical cells and cytokinin liberated by bacteria. The cells enlarge. A nodule is formed. In the infected cells of the nodule, the bacteria stop dividing and form polyhedral structures called **bacteriods.** Groups of bacteriods get surrounded by host membrane. In legume roots, a pinkish pigment called **leghaemoglobin** is formed over the bacterial mass.

10. Which of the following statements are true ? If false, correct them.

(a) Boron deficiency leads to stout axis.

(b) Every mineral element that is present in a cell is needed by the cell.

(c) Nitrogen as a nutrient element, is highly immobile in the plants.

(d) It is very easy to establish the essentiality of micronutrients because they are required only in trace quantities.

✓ (a) **True**

(b) **False.** Only some elements called essential elements are required.

(c) **False.** It is mobile.

(d) **False.** Micronutrients being trace elements are difficult to diagnose. They are often present as contaminants in materials of containers, water, cotyledons and alongwith macronutrients.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Name the enzyme involved in biological nitrogen fixation.

✓ Nitrogenase.

2. What is nitrification ?
   ✓ It is the phenomenon of conversion of ammonium nitrogen to nitrate nitrogen.
3. Which pigment is present in the root nodules of legumes ?
   ✓ Leghaemoglobin.
4. Name the best known symbiotic nitrogen fixing bacterium.
   ✓ *Rhizobium*.
5. What type of condition is created by leghaeomoglobin in the root nodule of a legume ?
   ✓ Anaerobic
6. How was it proved that minerals pass through xylem and not phloem ?
   ✓ By tracer technique (Stout and Hoagland, 1939)
7. What is primary dificiency ?
   ✓ Deficiency which is caused by criticial elements (N.P.K.)
8. Which is the most abundant element in plant body ?
   ✓ Oxygen
9. What are framework elements ?
   ✓ Elements involved in the synthesis of cell wall and storage materials *viz.* C, H, O.
10. Name the scientist who introduced hydroponics.
    ✓ Gericke (1940)
11. Pick out from the following list the two minerals which are not needed by the majority of plants but very much needed by almost all animals: Calcium, sodium, potassium, iron, iodine.
    ✓ Sodium, Iodine.
12. Match the words in Column I with phrases in Column II

Column I	*Column II*
(a) Magnesium	(i) found in middle lamella
(b) Sulphur	(ii) a structural component of chlorophyll
(c) Calcium	(iii) required for enzyme activity
(d) Iodine	(iv) found in some amino acids
(e) Manganese	(v) a component of sugars
	(vi) not important for plants.

✓(a)—(ii), (b)—(iv), (c)—(i), (d)—(vi), (e)—(iii)

One Mark Questions (Without Answers)

1. Name the pigments found in the root nodules of the leguminous plant.
2. How does leghaemoglobin protect the nitrogenase ?
3. Define the terms : (i) Hydroponics (ii) Micronutrients (iii) Macroelements (iv) Carnivorous plants (v) Nutrient.
4. Name the best known symbiotic nitrogen fixing bacterium.
5. Which are two micronutrients that play role in limiting plant growth usually ?
6. What is leghaemoglobin ?
7. Define biological nitrogen fixation.
8. What is conductive tissue for mineral nutrients in plants ?

Two Mark Questions (With Sample Answers)

1. List the macronutrients and mention their major function.
   ✓ C,H,O,N,P,K,S,Mg,Ca,Fe. These are involved in synthesis of organic molecules and development of osmotic potential.
2. What are the two macronutrients that usually play the most important role in limiting plant growth locally.
   ✓ Macronutrients which often become limiting in plant growth are called **critical elements.** They are three in number (N, P, K). Two of them are nitrogen and phosphorus. Their availability in soil is generally lower than the amount required by plants.

Two Mark Questions (Without Answers)

1. Name a chelate. Why is iron added in hydroponics along with chelating agent ?
2. Why do farmers use leguminous crops to provide nitrogen to the soil ? Explain.
3. Prior to sowing rice, a legume crop was cultivated and ploughed back in the field, why ? Explain.

4. Name the organism that fixes nitrogen in symbiotic association with a water fern. Where does it live in such plants.
5. A farmer adds *Azotobacter* culture to the soil before sowing maize. How does it increase the yield of maize ?
6. Describe an experiment that was used to prove that xylem translocates minerals.
7. What is hydroponics ? Give one application of this technique.
8. Name the respective mineral nutrient element that (i) forms the core constituent of the ring structure of chlorophyll (ii) activates carboxylases (iii) forms the component of nitrogenase (iv) synthesises middle lamella of plant cells.

Three Mark Questions (Short Answer Type)

1. Differentiate between macroelements and microelements.
2. What is 'dieback' ? Name the element which results in this malformation in its deficiency.
3. Why do plants need Potassium and Magnesium ?
4. If you grow a potted plant that initially weighed 200g and eventually weighed 50kg would you expect the soil in the pot to change weight ? Explain.
5. What are various steps involved in the biological nitrogen fixation in plants ?
6. What are the criteria for an element to be considered as essential part of life ?
7. Differentiate between essential and nonessential mineral elements.
8. Name the nitrifying bacteria of the soil. Why are they called chemoautotrophs ?
9. Why do farmers use leguminous crops to provide nitrogen to the soil ? Explain.
10. Describe the mechanism of mineral absorption by ion-exchange method.
11. What is importance of minerals in plant life.

Five Mark Questions (Long Answer Type)

1. What are fertilizers ? Why are they needed ? What do you mean by NPK fertilizers ?
2. What are the indications for mineral deficiency in plants.
3. Differentiate between two types of absorption of minerals from soil through roots.
4. Explain symbiotic nitrogen fixation.
5. Describe two important functions each of K, Fe and Zn in green plants and also write deficiency symptoms of any two of them.
6. Make a table showing macroelements, region of plants in which required, functions and their deficiency symptoms.

Multiple Choice Questions (With Answers)

(1) Denitrification is carried out by (a) *Pseudomonas* and *Nitrococcus* (b) *Nitrosomonas* and *Nitrobacter* (c) *Nitrosomonas* and *Nitrococcus* (d) *Pseudomonas* and *Thiobacillus*. *(HPPMT 2011)*

(2) Which helps in absorption of phosphorus from soil by plants ? (a) *Glomus* (b) *Frankia* (c) *Anabaena* (d) *Rhizobium*. *(CBSE 2011)*

(3) Which one is not a free living nitrogen fixer ? (a) *Rhodospirillum* (b) *Azotobacter* (c) *Rhizobium* (d) *Bacillus*. *(HP PMT 2012)*

(4) Fot its activity, nitrogenase requires (a) light (b) manganese (c) super oxygen radicals (d) high input of energy. *(CBSE Main 2012)*

(5) Hydroponics is growing of plants (a) without soil (b) without organic matter (c) in water (d) all the above. *(AMU 2013)*

(6) The most abundant intracellular cation is (a) K^+ (b) Na^+ (c) Ca^{2+} (d) H^+ *(NEET 2013)*

(7) Deficiency symptom of nitrogen and potassium are visible first in (a) buds (b) roots (c) senescent leaves (d) young leaves. *(CBSE 2014)*

(8) Which of the following bacterium causes denitrification ?
(a) *Azotobacter* (b) *Nitrobacter* (c) *Nitrosomonas* (d) *Pseudomonas*. *(JKCET 2015)*

(9) The enzyme nitrogenase is a (a) Cu-Fe protein (b) Ni-Fe protein (c) Mo-Fe protein (d) Ni-Cu protein. *(AMU 2015, WB 2015)*

(10) In plants micronutrients are those which are needed less than or equal to the following amount per gram of dry matter (a) 0.1 mg (b) 0.1 g (c) 0.1 μg (d) 1.0 μg. *(Bihar 2016)*

Assertion and Reason Type Questions

In each of the following quetions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as–
*(A) If both **A** and **R** are true and **R** is the correct explanation of **A***
*(B) If both **A** and **R** are ture and **R** is not the correct explanation of **A***
*(C) If **A** is true but **R** is false.* *(D) If both **A** and **R** are false.*

1. **Assertion.** Stomata open and close in response to turgor changes.
Reason. *p*H changes are brought about by influx and efflux of H^+ ions.
(A) (B) (C) (D)

2. **Assertion.** Deficiency of sulphur causes chlorosis in plants.
Reason. Sulphur is a constituent of chlorophyll, proteins and nucleic acids. *(AIIMS 2004)*
(A) (B) (C) (D)

3. **Assertion.** Nitrogen fixing bacteria of legume root nodules survive in oxygen depleted cells.
Reason. Leghaemoglobin completely removes oxygen from nodule cells. *(AIIMS 2004)*
(A) (B) (C) (D)

4. **Assertion.** Deficiency symptoms of N, K and Mg are first visible in the senescent leaves.
Reason. Biomolecules containing these elements are broken down in the older leaves, making these elements available for mobilising to younger leaves. *(AIIMS 2014)*
(A) (B) (C) (D)

5. **Assertion.** Nitrogen is one of the most essential elements of the human body.
Reason. All types of prokaryotic organisms are able to fix nitrogen. *(AIIMS 2015)*
(A) (B) (C) (D)

6. **Assertion.** Atmospheric nitrogen gas is always fixed by nitrogen fixing microorganisms.
Reason. Decomposers release nitrogen gas from dead bodies of plants and animals. *(AIIMS 2016)*
(A) (B) (C) (D)

ANSWERS

Multiple Choice Questions (With Answers)

(1) —d (2) —a (3) —c (4) —d (5) —d (6) —a (7) —c (8) —d (9) —c (10) —a

Assertion and Reason Type Questions

(1) — C (2) —C (3) —C (4) —A (5) —C (6) —D

Chapter

13 Photosynthesis in Higher Plants

THEORY–a quick rundown

HISTORICAL PERSPECTIVE

Belgian physician, Jan Baptista van Helmont, did a simple experiment and concluded that all the substance of the plant was produced from water and none from the soil.

Joseph Priestley, you may recall, discovered oxygen in 1774, observed that a candle burning in a closed space – a bell jar, soon gets extinguished. Similarly, a mouse would soon suffocate in a closed space. He concluded that a burning candle or an animal that breath the air, both somehow, damage the air. But when he placed a mint plant in the same bell jar, he found that the mouse stayed alive and the candle continued to burn. hypothesized as follows: Plants restore to the air whatever breathing animals and burning candles remove.

Using a similar setup as the one used by, but by placing it once in the dark and once in the sunlight, Jan Ingenhousz (1730-1799) showed that sunlight is essential to the plant process that somehow purifies the air fouled by burning candles or breathing animals. Ingenhousz in an elegant experiment with an aquatic plant showed that in bright sunlight, small bubbles were formed around the green parts while in the dark they did not. Later he identified these bubbles to be of oxygen. Hence he showed that it is only the green part of the plants that could release oxygen. Shortly thereafter, a Swiss Scholar, Theodore de Saussure, found that water is an essential requirement for photosynthesis to occur.

It was not until about 1854 that Julius von Sachs provided evidence for production of glucose when plants grow. His later studies showed that the green substance in plants (chlorophyll) is located in special bodies (later called chloroplasts) within plant cells. He found that the green part in plants is where glucose is made, and that the glucose is usually stored as starch.

Now consider the interesting experiments done by T. W. Engelmann (1843-1909). Using a prism he split light into its spectral components and then illuminated a green alga, Cladophora, placed in a suspension of aerobic bacteria. The bacteria were used to detect the sites of O_2 evolution. He observed that the bacteria accumulated mainly in the region of blue and red light of the split spectrum. A first action spectrum of photosynthesis was thus described. It resembles roughly the absorption spectra of chlorophyll *a* and *b*.

A simplified equation of photosynthesis was given by C.B. van Niel of Stanford University, USA:

$$CO_2 + 2H_2O \xrightarrow[\text{Green plants}]{\text{Light Energy}} (CH_2O)_n + H_2O + O_2$$

Photosynthesis is an anabolic process of manufacture of organic compounds inside the chlorophyll containing cells from carbon dioxide and water with the help of sunlight as a source of energy. The water provides hydrogen for the synthesis of organic compounds. All the liberated oxygen comes from it.

$$6CO_2 + 12H_2O \xrightarrow[\text{Radiant energy}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Some bacteria use hydrogen donor other than water. Therefore, photosynthesis has been redefined as the anabolic process of manufacture of organic compounds inside the chlorophyll containing cells from carbon dioxide and hydrogen donor with the help of radiant energy.

In photosynthesis water is oxidised to O_2 and carbondioxide is reduced to carbohydrates.

RAW MATERIALS

1. **Carbon Dioxide.** In land plants, it is obtained from the atmosphere. Small quantities of carbonates are absorbed from the soil through the roots. Hydrophytes get carbon dioxide from the aquatic environment as bicarbonates. Bicarbonates are absorbed by these plants through their general surface.

2. **Water.** (i) Van Niel, while working on a type of photosynthetic bacteria, found that they required hydrogen sulphide for their photosynthesis. O_2 was not released. Sulphur globule accumulated as a waste product. It means that carbon dioxide did not split up as there was no evolution of oxygen. Hydrogen sulphide was broken down to provide hydrogen for reduction of carbon dioxide. Van Niel thus propounded that oxygen is evolved from water.

(ii) Robbin Hill, illuminated the isolated chloroplasts of *Stellaria media* in the presence of leaf extract or hydrogen acceptors (*e.g.*, ferricyanides, ferrioxalates) in the absence of carbon dioxide. The chloroplasts evolved oxygen.

The hydrogen acceptors are also called **hill oxidants** while the reaction involving the production of oxygen by the illuminated chloroplasts in the absence of CO_2 fixation is called **Hill reaction**. The natural hydrogen acceptor of Hill reaction is $NADP^+$.

$$2NADP^+ + 2H_2O \xrightarrow[\text{Light}]{\text{Chloroplast}} 2NADPH + 2H^+ + O_2\uparrow$$

(iii) Ruben and Kamen suspended *Chlorella* in water having nonradioactive heavy isotope of oxygen ^{18}O, instead of natural oxygen. It was illuminated. Oxygen evolved was found to be heavy isotope, ^{18}O. This is possible only if oxygen evolved during photosynthesis comes from splitting of water.

3. **Light.** Light is the visible part of electromagnetic radiations. Visible light consists of radiations having a wavelength between 390-760 nm (or 3900-7600 Å). It can be resolved into light of different colours – **violet** (390 – 430 nm), **blue or indigo** of early workers (430 – 470 nm), **blue-green or blue** of early workers (470 – 500 nm), **green** (500 – 580 nm), **yellow** (580 – 600 nm), **orange** (600 – 650 nm), **orange – red** (650 – 660 nm) and **red** (660 – 760 nm). Red light above 700 nm is called **far-red**. Radiations shorter than violet are called **ultra – violet rays.** Radiations longer

than red are called **Infra – red**. Discrete particles of light are called **photons**. They carry energy. The energy contained in a photon is termed as **quantum** (hγ). 80 – 90% of light falling on leaves is absorbed by them. The rest is reflected and transmitted. Blue and red regions of the light spectrum are the most effective in photosynthesis. Blue wavelengths of light have more energy while red wavelengths have lesser energy. Green light is the least effective in photosynthesis. The light transmitted by the tree canopy is rich in green light. Therefore, plants growing under the canopy of others have lower rates of photosynthesis.

4. Chloroplasts. **Discussed under Cell Structure.**

PHOTOSYNTHETIC PIGMENTS

They occur inside the chloroplasts (on photosynthetic thylakoids) and take part in absorption of light energy. They are of three main types – chlorophylls, carotenoids and phycobilins.

Chlorophylls

They are green, water insoluble pigments. Five types occur in plants other than bacteria – a, *b*, *c, d and e*. Out of these only two occur in the chloroplasts of higher plants, *a and b*. Chlorophyll *a* is found in all photosynthetic plants except bacteria. Hence, it is known as **universal photosynthetic pigment.** It is also called **primary photosynthetic pigment** because it performs primary reaction of photosynthesis or conversion of light into chemical or electron energy. Other photosynthetic pigments are known as **accessory pigments**. They absorb light energy of different wavelengths and hand over the energy to chlorophyll *a* through electron spin resonance. Chlorophyll *b* accompanies chlorophyll *a* in green algae and higher plants.

Chorophyll *c* occurs in brown algae, diatoms, dinoflagellates and chrysomonads. Chorophyll *d* is present in red algae. Chlorophyll *e* is present in yellow green algae. In all the above groups chlorophyll *a* is also present.

Bacteria possess two types of pigments – bacteriochlorophyll (subtypes *a, b, c, d* and *e)* and bacteriophaeophytin or bacterioviridin (= chlorobium chlorophyll). Bacteriochlorophyll *a* has an empirical formula of $C_{55}H_{74}O_6N_4Mg$ and molecular weight of 911. Bacteriochlorophyll is mainly found in purple photosynthetic bacteria while bacterioviridin occurs in green photosynthetic bacteria.

Chlorophyll *a* is bluish-green. It has an empirical formula of $C_{55}H_{72}O_5N_4Mg$ and molecular weight of 893. Chlorophyll *b* is olive green with an empirical formula of $C_{55}H_{70}O_6N_4Mg$ and molecular weight of 907. Both of them are soluble in a number of organic solvents but chlorophyll *a* is more soluble in petroleum ether while chlorophyll *b* is more soluble in 90% methyl alcohol because it is more hydrophilic. **Chlorophyll *b* constitutes about one-fourth of the total chlorophyll content.**

Chlorophyll has a tadpole like configuration with a head called **porphyrin** and a tail made up of long chain alcohol called **phytol**. Porphyrin is made up of four **pyrrole rings** which are linked by **methine** bridges (–CH=). Each pyrrole ring is made up of 5 atoms – 4 carbon and one nitrogen. The nitrogen lies towards the centre. A nonionic magnesium is held in the centre of porphyrin head by nitrogen atoms of pyrrole rings (through two covalent and two coordinate bonds). The external carbon atoms of the pyrrole rings have been given specific numbers, 1-8. Carbon atoms 1, 3, 5 and 8 have methyl groups ($-CH_3$). Carbon atom 2 possesses a vinyl group ($-CH = CH_2$) while carbon atom 4 has an ethyl group ($= CH_2 - CH_3$). Carbon atom 6 is attached to next methine group by a fifth isocyclic ring called cyclopentanone. Carbon atom 7 is connected to phytol tail through a propionic acid residue. **The phytol side chain, composed of insoluble carbon and hydrogen atoms helps to anchor the chlorophyll molecules with the thylakoids in the chloroplasts.**

Chlorophyll *b* differs from chlorophyll *a* in having formyl group (–CHO) instead of a methyl ($-CH_3$) group at carbon atom 3. Chlorophyll *b* is thus aldehyde of chlorophylla *a*.

Photoluminescence. It is the phenomenon of re-radiation of absorbed energy by an object. It is of two types: fluorescence and phosphorescence.

The normal state of an atom or a molecule is known as **ground state or singlet state**. When a photon collides with a molecule such as chlorophyll, it is said to be excited or activated. Its outer valence electron is pushed into a high-energy orbit and the molecule comes into **excited singlet state**. This state of a molecule is unstable having a very short half-life. The electron tends to fall back in one of the several ways.

The electron may immediately release energy in the form of radiation and come to its ground state. This release of radiation energy is known as fluorescence. In most cases of florescence, absorption of light of a smaller wavelength induces emission of light with a larger (less energetic) wave length. The energy difference between the absorbed and the emitted photons is dissipated in the florescent material via internal molecular vibrations and eventually heat. The most striking example of this phenomenon occurs when the absorbed photon is in the UV region and is thus invisible, and emitted light is in the visible region. All photosynthetic pigments have the property of fluorescence. **Chlorophyll shows an outburst of fluorescence during the first few moments of illumination. This is called Kutusky effect.** Most of the fluorescence emitted by photosynthetic organs is due to chlorophyll *a* because other pigments usually hand over their absorbed energy to it through resonance. Chlorophylls usually show red fluorescence though they absorb blue radiations as well.

At times the electron loses a small amount of energy in the form of heat and comes to lie in a less excited state called triplet excited state. This state is again unstable. The electron may fall back to ground state from triplet state by losing radiation energy. This delayed emission of long wave radiations from an irradiated and activated molecule is called phosphorescence.

Sometimes the electron picks up more energy than the excited singlet state. It is called second singlet state. It remains in this state for a very brief period before coming to excited singlet state.

READ AND DIGEST

The rate or yield of photosynthesis is measured as number of O_2 molecules produced per quantum of light absorbed. This is called quantum yield. Its reciprocal term is quantum requirement, *i.e.*, the number of light quanta needed for the production of one molecule of oxygen. It has been found that the reduction of one molecule of CO_2 to carbohydrate and the liberation of one molecule of O_2 requires a minimum of 8 quanta of light. Thus, the quantum requirement of photosynthesis is 8 quanta. The quantum yield is, therefore, about 1/8 or 12%.

Emerson Effect. Emerson found a sharp reduction in the rate of photosynthesis when monochromatic beam of more than 680 nm was used alone. It is called **Emerson's first effect or red drop.** He observed that rate can be enhanced if monochromatic beams of two different wavelengths (long and short) were applied simultaneously. It is more than the sum total of photosynthesis carried out separately by two light beams.

The phenomenon is called **Emerson second effect or photosynthetic enhancement**. Emerson effect is common in those organisms only which liberate oxygen during their photosynthesis. Emerson effect can be due to two reasons:

(a) Photosynthetic pigments occur in specific groups called **light harvesting groups** or **energy traps.** Each such group has a **trap centre,** which is made up of a special chlorophyll *a* molecule. The trap centre has a high frequency of excitation, which can be fully utilized only when all the collaborating molecules get excited by light energy. Some of the collaborating molecules absorb the short wavelengths.

(b) There are two inter-connected pigment systems, each having its own requirement of light

energy. Different light beams (say light 1 and 2) will excite different pigment systems (PS-I and PS-II) to various extents. Some of the pigment molecules are similar in the two systems. Therefore, with a light beam of only one type one, or the other system will work below its maximum efficiency. But when the two types of light beams are applied simultaneously or alternately at short intervals, an enhancement in photosynthesis takes place because of the optimum working of both the systems.

It is, therefore, clear that Emerson effect is due to the presence of two photo systems carrying out different photoreactions.

Absorption Spectrum. The curve showing the amount of different wavelengths of light absorbed by a substance is called **absorption spectrum**. It is studied with the help of **spectrophotometer**. The absorption spectra of chlorophylls *a* and *b* show that they absorb maximum light in the blue-violet and red wave-lengths. This portion of the spectrum between 400nm and 700nm is also referred to as **Photosynthetically active radiation (PAR)**. The pigments are often known after the wavelength, which is absorbed to the maximum, *e.g.*, $Chla_{660\text{-}670}$, $Chla_{670\text{-}680}$, $Chla_{690\text{-}700}$, P_{680}, P_{700}. The exact positions of peaks depend upon the solvent in which the pigments are dissolved. The absorption peaks of chlorophylls in the blue-violet region are called soret bands.

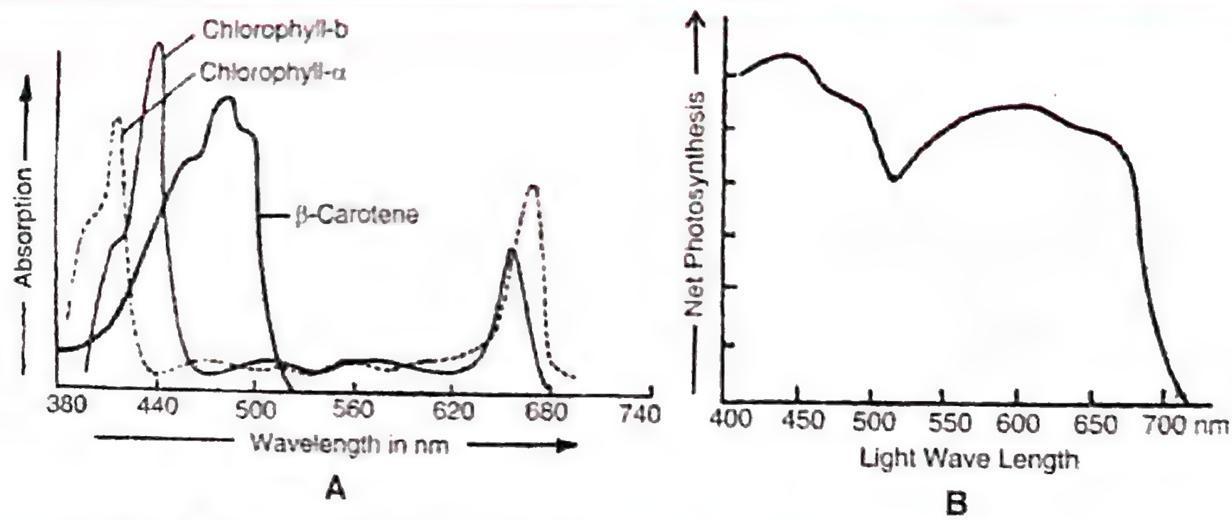


Fig. 13.1. Absorption and action spectra. A, Absorption spectra of three photosynthetic pigments (chl *a*, chl *b* and β-carotene). B, action spectrum of photosynthesis (relative rates of photosynthesis at different wavelengths of light).

Action Spectrum. The curve depicting the relative rates of photosynthesis at different wave-lengths of light is called action spectrum. It shows that maximum photosynthesis occurs in blue-violet and red parts of the light. Action spectrum follows closely the absorption spectra of chlorophylls *a* and *b* proving that the latter are the main photosynthetic pigments. Sufficient photosynthesis also occurs in the mid part of the light spectrum where carotenoids are active.

Carotenoids

They are a group of yellow, brown, orange and red coloured water insoluble pigments, which are associated with the chlorophylls inside the chloroplasts and alone inside the chromoplasts. Along with chlorophyll *b* the carotenoids are also called accessory pigments because they hand over the energy absorbed by them to chlorophyll *a*. **No light is required for their formation. This is the reason that plant seedlings grown in darkness develop only yellowish colour of carotenoids. The autumnal yellow brown colouring of leaves is a result of degeneration of chlorophylls and the unmasking of carotenoids.** Structurally, carotenoids are related to phytol, which forms a non-green tail of chlorophyll. They have unsaturated molecules built up of isoprene units. They have

got conjugated double bonds between carbon atoms. Carotenoids absorb light in blue and green parts of the spectrum. They possess the property of fluorescence and emit light belonging to orange and red parts of spectrum. They are of two types: carotenes and Xanthophylls. The common names of carotenes end with ene and those of Xanthophylls end with in. **Most of the carotenes are present in the pigment system I and xanthophylls in pigment system II.**

(a) **Carotenes.** They have a general formula of $C_{40}H_{56}$. The fundamental type seems to be lycopene which is red in colour and has an open chain. It is found in purple sulphur bacteria and in the tomato, fruits, roses, chillies etc. Carotene which is isomeric with lycopene is orange-yellow in colour. There are three main isomers of carotene known as α, β and γ. β-carotene is the most abundant of all these and is invariably found in chloroplasts. α-carotene is found in all green plants while γ-carotene is found in green Sulphur bacteria. β-carotene is converted to vitamin A by animals. β-carotene is capable of absorbing light in violet and blue-green parts of the spectrum.

Besides leaves, carotenes are found in the flowers and fruits of several plants. The color of carrot roots is also due to them.

(b) **Xanthophylls (Carotenols).** They are yellow or brown oxygen containing derivatives of carotenes. Lutein or luteol ($C_{40}H_{56}O_2$) is the most common Xanthophyll of leaves and some flowers. Other common leaf xanthophylls are zeaxanthin (isomer of lutein), cryptoxanthin, flavoxanthin and violoxanthin. Brown algae have fucoxanthin ($C_{40}H_{56}O_6$), which provides characteristic colour to them. Violoxanthin is the second major xanthophyll of higher plants.

Most of the Xanthophylls differ from carotenes in that they are only slightly soluble in carbon disulphide. The absorption spectrum of xanthophyll is similar to that of carotenes, with peak in the blue region and some absorption in violet region of the spectrum.

Functions

(i) Carotenoids act as accessory pigments. They absorb energy in the mid region of visible spectrum and hand over the same to chlorophyll.

(ii) They protect the chloroplast constituents from nascent oxygen released during photolysis of water. Carotenoids pick up nascent oxygen by means of their double bonds and change the same into harmless molecular state.

(iii) By their colour, they make the flowers and fruits attractive to animals for pollination and dispersal.

(iv) β-carotene produces vitamin A in animals.

(v) Carotenoid may play some role in regulating phototropic responses through changes in their double bonds.

(vi) Unbranched excited state of chlorophyll reacts with molecular oxygen to form a highly damaging excited state of oxygen called singlet oxygen (O_2). Carotenoids prevent this by quenching the excited state of chlorophyll.

(vii) Three xanthophylls (violoxanthin, antheroxanthin and zeaxanthin) take part in dissipation of excess energy by conversion of the same into heat.

Phycobilins

They are photosynthetic pigments of some algal groups, which are structurally related to bile pigments. They are open tetrapyrroles which neither contain magnesium nor phytol. They are water soluble pigments. They are of three types— phycocyanin, phycoerythrin and allophycocyanin. Phycocyanin and allophycocyanin are blue in colour while phycoerythrin is red. They are important accessory pigments of blue-green algae, red algae and cryptomonads. The light radiations are passed in the following sequences

Phycoerythrin – Phycocyanin – Allophycocyanin – Chlorophyll *a*

All the pigments are conjugated to proteins. Because of their association with proteins the pigments are also called phycobiliproteins or biliproteins. **In cryptomonads, they are found inside the thylakoids but in others they lie outside the thylakoids in small organelles called phycobilisomes.** The phycobilisomes occur in contact with thylakoids. This allows transfer of radiation energy from phycobilins to chlorophyll *a* molecules situated inside the thylakoids.

The phycobilins absorb light at various wavelengths, especially the shorter ones (including UV rays). **This is an adaptation to the aquatic habitat where longer light waves do not penetrate.**

PHOTOSYNTHETIC UNITS (PSU)

It is the smallest group of pigment molecules, which take part in conversion of light energy into chemical energy. It has a **photocentre** or **trap centre** or **reaction centre,** which is fed by about 200 **harvesting pigment molecules**. The photocentre consists of chlorophyll *a* molecule. It absorbs light at longer wavelengths. The harvesting molecules are of two types, **antenna molecules** and **core molecules.**

The antenna molecules absorb light of shorter wavelength than that of photocentre. On absorption of light energy the antenna molecules get excited. The excited antenna molecules hand over their energy to core molecules. The energy picked up by core molecules is supplied to the photocentre. On absorption of energy the photocentre gets excited and extrudes an electron after which it comes to ground state to repeat the cycle. The frequency of excitation of photocentre is very high. It cannot be met by its direct absorption of sun energy. Also, the absorption of light of shorter wavelengths cannot be done by it directly. Therefore, it requires the help of harvesting molecules. Another requirement is the regular supply of electrons from another system.

Photosynthetic units are equivalent to quantasomes suggested by Park. Quantasomes are minute separable structures of chloroplast thylakoids. They are large enough to contain about 230 chlorophyll to form a PSU. However, the functional significance of quantasomes is doubtful.

Photo Systems or Pigment Systems

Photosynthetic units occur in the form of two distinct **Light Harvesting Complexes (LHC)** called photo systems or pigment systems. Green plants possess two photosystems, I and II. **These are named in the sequence of their discovery, and not in the sequence in which they function during the light reaction. Each Photosystem has all the pigments (except one molecule of chlorophyll a). Anoxygenic photosynthetic bacteria possess a single photosystem where the reaction centre is similar to that of Photosystem II. About 250 to 400 pigment molecules constitute a single photosystem.**

Differences between Photosystem I and Photosystem II

Photosystem I	*Photosystem II*
1. It is located in the nonappresed part of grana thylakoids as well as stroma thylakoids.	1. It is present in the apprised part of grana thylakoids.
2. Chlorophyll : carotenoid content is 20-30:1.	2. Chlorophyll to carotenoid ratio is 3–7 : 1.
3. Chlorophyll *a* content is more than twice that of chlorophyll *b*.	3. Chlorophyll *a* and chlorophyll *b* are approximately equal in amount.
4. Its photocentre is P_{700}.	4. Its photocentre is P_{680}.
5. It receives electrons from photosystem II.	5. Electrons are received from photolytic reaction.
6. Normally it hands over its electron to $NADP^+$.	6. Normally it hands over its electrons to PS I.

7. Photosystem I can perform cyclic photophosphorylation independently.	7. It performs non-cyclic photophosphorylation in conjunction with photosystem I.
8. It is not connected with photolysis of water.	8. Photosystem II is connected with photolytic oxidation of water.
9. It has a reducing agent X, ferrodoxin, Fe-S protein, plasto quinine, plastocyanin and cytochromes f and b563.	9. It contains Mn^{2+}, Cl^-, quencher molecule Q, plastoquinone, plastocyanin, cytochromes f and b_{559}.
10. Iron-sulphur proteins called Fe-S are supposed to be the primary acceptor of electrons.	10. Substance Q. (quinine) is supposed to be the primary acceptor of electrons.

PHOTOPHOSPHORYLATION

It is the light driven synthesis of ATP. It is of two main types, noncyclic and cyclic.

1. Noncyclic or Linear Photophosphorylation

The electron expelled by the excited photocentre does not return to it. ***Non-cyclic photophosphorylation is also called Z-scheme, due to its characteristic shape.*** It is carried out in collaboration of both photosystems II and I. Electron released during photolysis of water is picked up by photocentre of PS II, which is located on the inner side of the membrane of the thylakoid.

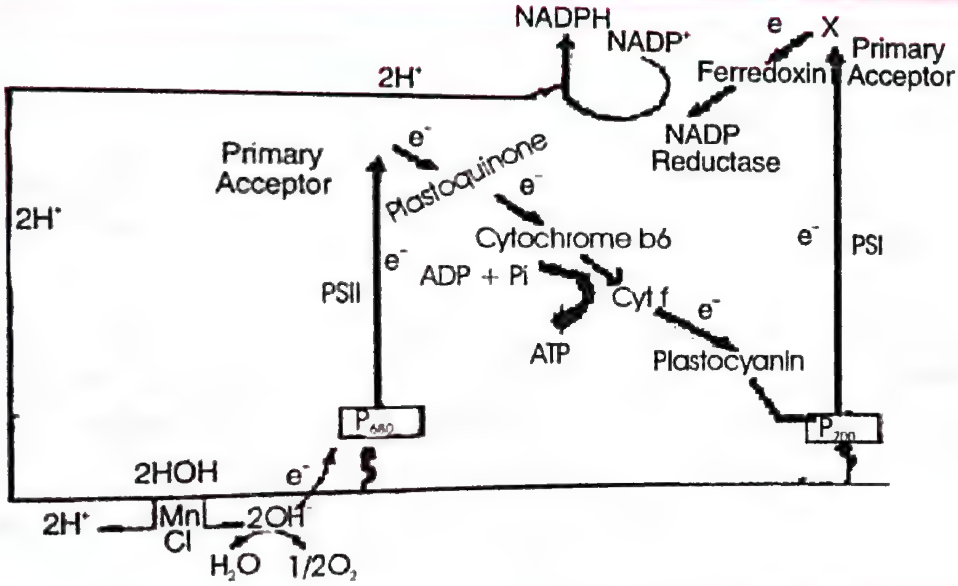


Fig. 13.2. Non-cyclic photophosphorylation and electron transport during photochemical phase.

The same is extruded out when the photocentre absorbs light energy (h½). The extruded electron has energy equivalent to 23 kcal/mole. It passes through a series of electron carriers. The process of expulsion of electron from photocentre is called primary reaction of photosynthesis and it involves quantum conversion (*i.e.*, conversion of light energy into chemical energy). However, it must be remembered that the first step in non-cyclic photophosphorylation is absorption of light energy by pigments of PS II. As a result of energy absorption, the photocentre becomes photoexcited and exudes an electron, which is accepted by primary acceptor **(Pheophytin).** The oxidized photocentre comes to ground state by receiving electron from photo-oxidation of water via an unknown compound Z. **Manganese, calcium and chloride ions play prominent roles in photolysis of water.**

2. Cyclic Photophosphorylation

An electron expelled by the excited photo centre is returned to it after passing through a series of electron carriers. It is performed by photosystem I only. Its photocentre P_{700} extrudes an electron with a gain of 23 kcal/mole of energy after absorbing a photon of light (hν).

When non-cyclic photophosphorylation is stopped under certain conditions, cyclic photophosphorylation occurs. The non-cyclic photophosphorylation can be stopped by illuminating isolated chloroplasts with light of wavelengths greater than 680nm. By this way, only photosystem I is activated, as it has a maximum absorption at 700nm, and photosystem II, which absorbs wavelengths of 680nm, becomes inactivated. Due to the inactivation of photosystem II, the electron flow from water to NADP is stopped and CO_2 fixation is also retarded. When CO_2 fixation is stopped, electrons will not be removed from the reduced NADPH. Thus NADPH will not be oxidised and NADP will no longer be available as an electron acceptor. Under these circumstances, cyclic photophosphorylation occurs.

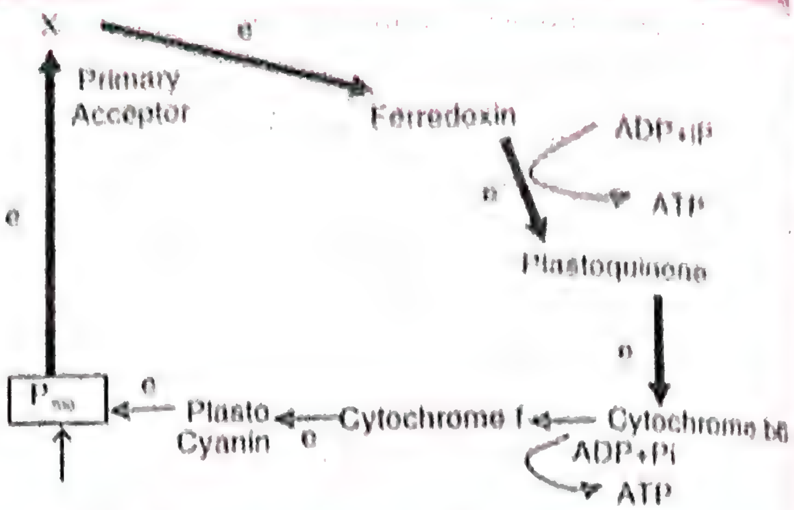


Fig. 13.3. Cyclic photophosphorylation.

Halobacteria or halophile bacteria also perform photophosphorylation but ATP thus produced is not used in synthesis of food. These bacteria possess purple pigment bacteriorhodopsin attached to plasma membrane. As light falls on the pigment, it creates a proton pump, which is used in ATP synthesis. These bacteria are anaerobes and cannot carry out normal oxidative phosphorylation. This process also takes place in the illuminated leaves of high plants under low light intensity and reduced CO_2 supply.

Differences between Cyclic and Non-Cyclic Phoophosphorylation

Cyclic Photophosphorylation	*Non-Cyclic Photophosphorylation*
1. It is performed by photo system I independently.	1. It is performed by collaboration of both photo systems II and I.
2. An external source of electrons is not required, as the same electrons get recycled.	2. An external electron donor is required.
3. It is not associated with photolysis of water. Therefore, no oxygen is evolved.	3. It is associated with photolysis of water and liberation of oxygen.
4. It synthesizes only ATP.	4. It is not only connected with ATP synthesis but also production of NADPH.
5. It operates under low light intensity, anaerobic conditions or when CO_2 availability is poor.	5. It takes place under optimum light, aerobic conditions and in the presence of carbon dioxide.
6. The system does not take part in photosynthesis except in certain bacteria.	6. The system is connected with CO_2 fixation (by producing reducing power) in all plants including blue green algae.
7. It occurs mostly in stromal or intergranal thylakoids.	7. It occurs in the granal thylakoids.
8. It is not affected by herbicide DCMU (Dichlorophenyl dimethyl urea).	8. DCMU inhibits noncyclic photophosphorylation.

Chemiosmotic Hypothesis

Let us now try and understand how actually ATP is synthesized in the chloroplast. The chemiosmotic hypothesis has been put forward to explain the mechanism. Like in respiration, in photosynthesis too, ATP synthesis is linked to development of a proton gradient across a membrane. This time these are membranes of the thylakoid. There is one difference though; here the proton accumulation is towards the inside of the membrane, *i.e.*, in the lumen. In respiration, protons accumulate in the intermembrane space of the mitochondria when electrons move through the ETS.

Let us understand what causes the proton gradient across the membrane. We need to consider again the processes that take place during the activation of electrons and their transport to determine the steps that causes a proton gradient to develop.

(a) Since splitting of the water molecule takes place on the inner side of the membrane, the protons or hydrogen ions that are produced by the splitting of water accumulate within the lumen of the thylakoids.

(b) As electrons move through the photosystems, protons are transported across the membrane. This happens because the primary accepter of electron which is located towards the outer side of the membrane transfers its electron not to an electron carrier but to an H carrier (this carrier is most probably plastoquinone). Hence, this molecule removes a proton from the stroma while transporting an electron. When this molecule passes on its electron to the electron carrier on the inner side of the membrane, the proton is released into the inner side or the lumen side of the membrane.

(c) The NADP reductase enzyme is located on the stroma side of the membrane. Along with electrons that come from the acceptor of electron of PS I, protons are necessary for the reduction of $NADP^+$ to NADPH + H^+. These protons are also removed from the stroma.

Hence, within the chloroplast, protons in the stroma decrease in number, while in the lumen there is accumulation of protons. This creates a proton gradient across the thylakoid membrane as well as a measurable decrease in pH in the lumen. It has been estimated that the pH of outside medium becomes around 8 whereas that of thylakoid lumen around 5, i.e., H^+ concentration inside the lumen becomes 1000 times as great as in the stroma (Srivastava).

Why are we so interested in the proton gradient ? This gradient is important because it is the breakdown of this gradient that leads to release of energy. The gradient is broken down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the F_0 of the ATPase. The ATPase enzyme (also known as coupling factor, (F) consists of two parts— one called the F_0 (or stalk) is embedded in the membrane and forms a transmembrane channel that carries out facilitated diffusion of protons across the membrane. The outer portion is called F_1 (or knob) and protrudes on the outer surface of the thylakoid membrane on the side that faces the stroma. The break down of the gradient provides enough energy to cause a conformational change in the F_1 particle of the ATPase, which makes the enzyme synthesize several molecules of energy-packed ATP. It must be remembered that ATPase is also associated with the destruction of ATP, but will operate in the reverse situation as long as sufficient energy is supplied (Devlin).

Chemiosmosis requires a membrane, a proton pump, a proton gradient and ATPase. Energy is used to pump protons across a membrane, to create a gradient or a high concentration of protons within the thylakoid lumen. ATPase has a channel that allows diffusion of protons back across the membrane; this releases enough energy to activate ATPase enzyme that catalyses the formation of ATP.

Thus, in short we can conclude that Photolysis of water takes place in the thylakoid interior and ATP and NADPH synthesis takes place on the stroma side surface of the thylakoid.

READ AND DIGEST

There are sufficient evidences that $8H^+$ are released by non-cyclic electron transport (*i.e.*, 4 from H_2O oxidation and 4 from plastoquinone (PQ) function and $4H^+$ by cyclic electron transport (through $PQH_2 \rightarrow PQ$). Thus a total of $12H^+$ are released into the inner space when 2 molecules of H_2O are oxidized, one molecule of O_2 is evolved and 2 molecules of $NADP^+$ are reduced. Single molecule of ATP is formed for every $3H^+$ passing through ATPase complex. Thus about 4 ATP molecules will be formed for $12H^+$ released during non-cyclic and cyclic electron transport. These ATP molecules are just enough to fix one molecule of CO_2 into a sugar phosphate.

According to Devlin, evolution of 1 mole of O_2 is accompanied by the reduction of 2 moles of NADP and esterification of 2 moles of ADP.

MECHANISM OF PHOTOSYNTHESIS

Photosynthesis occurs in two phases – **photochemical and biochemical.**

Photochemical Phase (Light or Hill Reaction)

The light driven reaction of photosynthesis, referred to as **electron transport chain**, was first formulated by Robert Hill. It occurs inside the thylakoids, especially those of grana region. It is dependent upon light. Its function is to produce **assimilatory power** consisting of reduced coenzyme NADPH and energy rich ATP molecules. It involves the following reactions:

(a) Photolysis of Water. Light energy, independent of pigment system, is utilized most probably for activating enzyme complex Z. Water dissociates into hydrogen and hydroxyl ions.

$$4H_2O \rightleftharpoons H^+ + 4OH^-$$

$$4OH^- \xrightarrow[Mn^{2+},\,Cl^-]{\text{Z-complex}} 2H_2O + O_2 - + 4e^-$$

(b) Production of Assimilatory Power (NADPH & ATP). Same as non-cyclic photophosphorylation.

Biosynthetic Phase (Dark or Blackman's Reaction)

It does not require light. The assimilatory power produced during photochemical phase is used in fixation and reduction of carbon dioxide. *The enzymes for the process are present in the matrix or stroma of the chloroplast.* These reactions of this phase are referred to as **carbon reactions.** There are three main pathways of CO_2 fixation— Calvin cycle, C_4 dicarboxylic acid cycle and Crassulacean acid metabolism. The plants exhibiting these are respectively called C_3, C_4 and CAM plants. There is no taxonomic importance of the pathways. Thus *Euphorbia corollata* is a C_3 plant while *Euphorbia maculata* is C_4 plant. Grass *Alloteropsis semi-alata* has both C_3 and C_4 ecotypes (ecological variants).

Calvin Cycle (Calvin-Benson Cycle, Reductive Pentose Pathway, C_3 cycle or Photosynthetic Carbon Reduction (PCR) Cycle). The cycle was discovered by Calvin and Benson. Calvin received Nobel Prize for his discovery. They fed *Chlorella and Scenedesmus* with radioactive ^{14}C in carbon dioxide. Radioactive carbon, ^{14}C has a half-life of 5200 years. Therefore, the path of CO_2 fixation can be easily traced with its help. The technique used is called **autoradiography**.

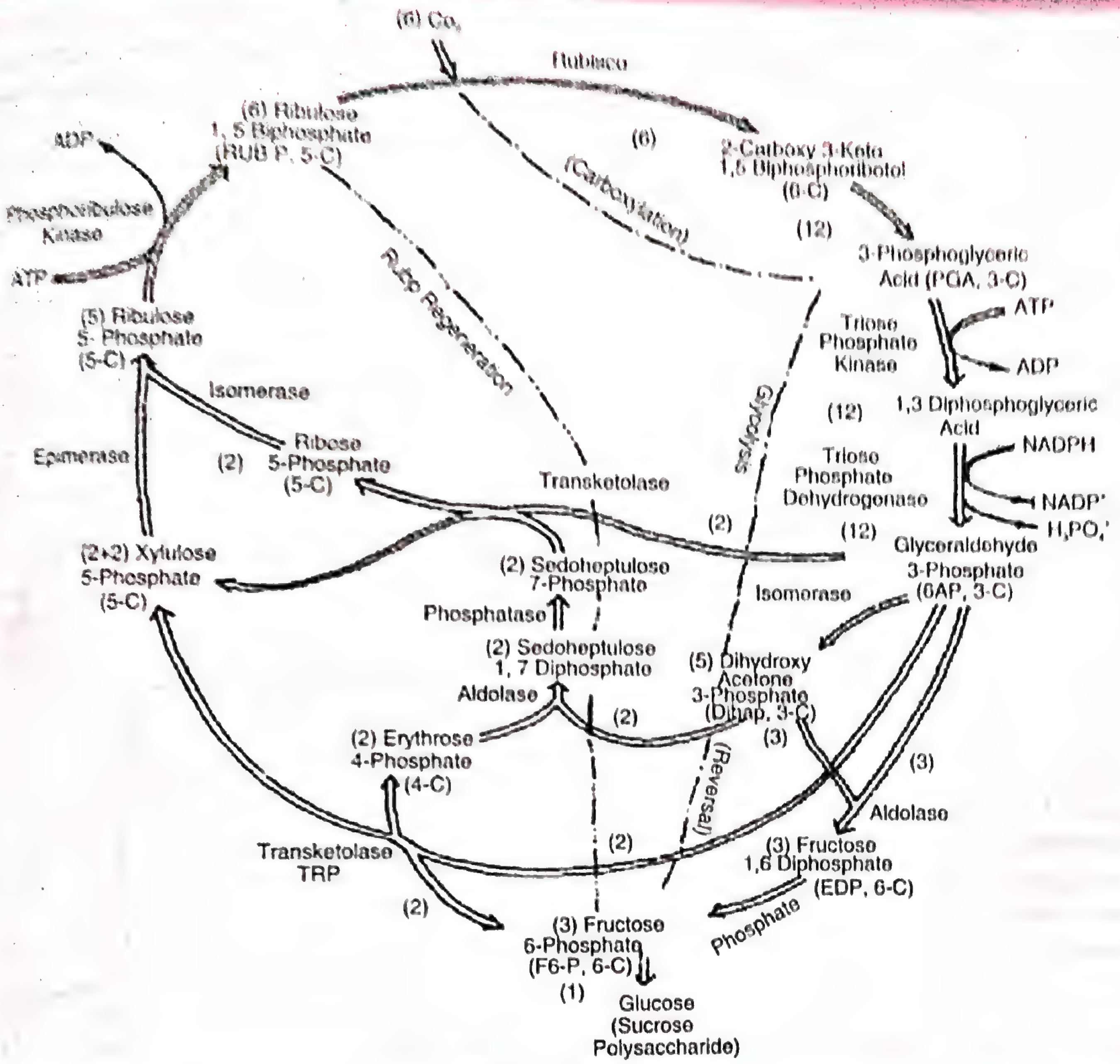


Fig. 13.4. Calvin Cycle.

Calvin found that after three seconds, radioactivity appeared in phosphoglyceric acid or PGA. Phosphoglyceric acid is, therefore, the first stable product of photosynthesis. Radioactivity was also found out to be present in only one carbon of this compound which happened to be the first one.

Apparently only the first carbon group of the chemical came from CO_2 while the rest were contributed by some acceptor molecule. The acceptor molecule was found out to be ribulose – 1, 5 biphosphate.

Phases of Calvin Cycle. Calvin cycle is divided into the following three phases – carboxylation, glycolytic reversal and regeneration of RuBP.

Carboxylation requires ribulose – 1, 5-biphosphate or RuBP as **acceptor** of carbon dioxide and copper containing **RuBP carboxylase or rubisco** as enzyme. The enzyme was previously called **carboxydismutase.** Rubisco is the most abundant protein of the biological world. **It is located on the outer surface of thylakoid membrane.** As rubisco also possesses oxygenase activity, it is also called ribulose biphosphate carboxylase oxygenase.

Carbon dioxide combines with ribulose – 1, 5 biophosphate to produce a transient intermediate compound called 2-carboxy 3-keto 1, 5 biphosphoribotol. It splits up immediately to form the two molecules of **3-phosphoglyceric acid** or PGA. It is the first stable product of photosynthesis.

As glucose is a six-carbon compound, six turns of Calvin cycle are required to synthesise its one molecule.

The net reaction of C_3 dark fixation of carbon dioxide is

$$6\ RuBP + 6CO_2 + 18\ ATP + 12\ NADPH \longrightarrow 6\ RuBP + C_6H_{12}O_6 + 18\ ADP + 18\ P + 12\ NADP^+$$

PHOTORESPIRATION. (PCO cycle or Photosynthetic Carbon Oxidative cycle)

It is the respiration associated with photosynthetic tissues. It is the light dependent utilization of oxygen and release of carbon dioxide by the photosynthetic organs. The photosynthetic organs do the reverse in the light. Therefore, photorespiration is difficult to demonstrate. It is inferred from (i) Decrease in the rate of photosynthesis when oxygen concentration is increased from 2-3% to 21% (ii) Sudden increased evolution of CO_2 when an illuminated green organ is transferred to dark.

Its site is chloroplast. Peroxisome is also required. RuBP carboxylase is changed to **RuBP oxygenase.** It occurs at high temperature and high oxygen concentration. Under these conditions, the affinity of RuBP carboxylase for CO_2 decreases and that for O_2 increases. High temperature occurs in tropical areas. Therefore, tropical plants are the major sufferers. At high temperature, RuBP carboxylase functions as oxygenase and instead of fixing carbon dioxide, oxidises ribulose 1, 5-biphosphate to produce phosphoglyceric acid and phosphoglycolate.

Phosphoglyceric acid or PGA is used up in Calvin cycle. Phosphoglycolate is hydrolysed (dephosphorylated) to form glycolate or glycolic acid. It is generally regarded that glycolic acid serves as the primary substrate for photorespiration. It is so because the carboxyl group of glycolic acid is the source of photorespiratory CO_2 or we can say the metabolism of glycolic acid leads to the production of photorespiratory CO_2. Glycolate usually passes into **peroxisome** of the mesophyll cell where it is oxidized to glyoxylate. Glyoxylate is aminated and gives rise to amino acid glycine. Glycine enters **mitochondrion**. Here two molecules of glycine condense to form a molecule of serine. CO_2 and ammonia are released in the process. Serine is taken up by peroxisome and deaminated to form glycerate. The latter passes into chloroplasts for synthesis of photosynthetic products as well as photorespiration. Since photorespiration involves the synthesis of two-carbon compounds, it is also called **C_2 cycle.**

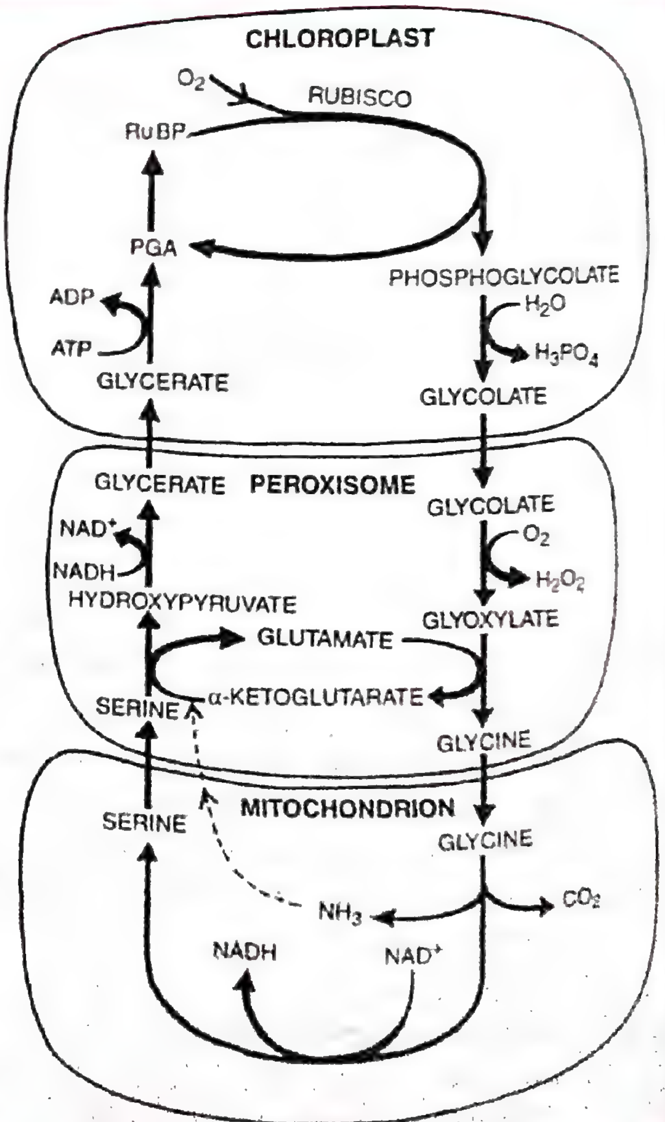


Fig. 13.5. Mechanism of photorespiratory carbon oxidation cycle.

In photorespiration two molecules of phosphoglycolate (*i.e.*, 4 carbon atoms) formed by oxygenation of RuBP is changed into 1 molecule of phosphoglycerate (PGA) and one molecule of CO_2. In other words 75% of carbon lost during oxygenation of RuBP is recovered by photorespiratory carbon oxygenation or PCO cycle.

Photorespiration does not produce energy. Rather, it consumes energy. It undoes the work of photosynthesis. It may reduce photosynthesis by 50%. Therefore, it is a highly wasteful process. It occurs only in case of C_3 plants. C_4 plants have overcome the problem of photorespiration by performing Calvin Cycle in the interior of leaves (bundle sheath cells) where temperature and oxygen (as the light reaction takes place in mesophyll cells) are lower. They have ensured high CO_2 supply to cells performing Calvin cycle.

Under conditions of high light and limited CO_2 supply, photorespiration has a useful role in protecting the plants from photooxidative damage. This means that if enough CO_2 is not available to utilize light energy for carboxylation to proceed, the excess energy causes damage to plants. However, photorespiration, that is oxygenation of RuBP, utilizes part of the light energy and saves the plant from the photooxidative damage. Photorespiration also helps in dissipation of energy where stomata get closed during daytime because of water stress.

Photorespiration increases with increase in (i) Intensity of light. (ii) Concentration of oxygen (iii) Temperature and (iv) Age of the leaf. Photorespiration is enhanced when CO_2 is limiting photosynthesis. If CO_2 concentration is increased, the net photosynthesis is enhanced and photorespiration seems to get depressed. **So we can say that relative levels of O_2 and CO_2 determine the occurrence of photorespiration, since both gases compete for the same active site of Rubisco.** It has no relation with normal respiration. In order to differentiate, normal respiration is often called **dark respiration** though the latter occurs in the illuminated cells as well.

C_4-Dicarboxylic Acid Pathway (Hatch Slack Pathway, C_4 Pathway)

First of all Kortschak found that labelled carbon dioxide ($^{14}CO_2$) assimilated by Sugarcane leaves first appeared in a 4-carbon compound oxalo-acetic acid. Hatch and Slack found it to be a regular mode of CO_2 – fixation in a number of tropical plants, both monocots and dicots, *e.g.*, Maize, Sugarcane, Sorghum, Pearl millet, *Amaranthus, etc.* These plants are called C_4 plants because of the first stable photosynthetic product being a 4-carbon compound. They often live in xerophytic and saline habitats. They have **Kranz anatomy.** "Kranz' means wreath and is a reflection of the arrangement of cells. In Kranz anatomy, the mesophyll is undifferentiated and its cells occur in concentric layers around vascular bundles having large bundle sheath cells. The mesophyll and bundle sheath cells are connected by plasmodesmata. The chloroplasts of the mesophyll cells are smaller. They have well developed grana and a peripheral reticulum but no starch.

Mesophyll cells are specialised to perform light reaction, evolve O_2 and produce assimilatory power (ATP and NADPH). They also possess enzyme for initial CO_2 fixation. The chloroplasts of the bundle sheath cells are larger and possess a peripheral reticulum and starch grains. **Bundle sheath cells are characterized by a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces.** They either have ill defined grana or lack grana.

In agranal chloroplasts thylakoids occur as stromal lamallae. ATP can be synthesised through cyclic photophorylation. However photolysis and O_2 evolution are absent (as PS II is absent). Thus we can see that O_2 release takes place in mesophyll cells and CO_2 fixation in bundle sheath cells. This type of arrangement does not allow O_2 released in mesophyll cells to escape to bundle-sheath cells. Thus, Rubisco, which is present only in bundle sheath cells, does not come into contact with O_2 and as a result, oxygenation of RuBP is completely avoided. To further reduce the occurrence of

photorespiration, C_4 plants have a CO_2 concentrating mechanism which builds up high concentration of CO_2 in the vicinity of Rubisco in the bundle sheath cells. High concentration of CO_2 near Rubisco favours carboxylation and suppresses photorespiration. (C_4 plants exhibit very low rates of photorespiration in bundle sheath cells – Devlin).

In C_4 plants, **initial fixation** of carbon dioxide occurs in mesophyll cells. The **primary acceptor** of CO_2 is **phosphoenol pyruvate** or PEP. It combines with carbon dioxide in the presence of PEP carboxylase or **pepco** or **PEP Case** to form oxalo-acetic acid or oxaloacetate. Oxaloacetate is converted to malic acid or aspartic acid.

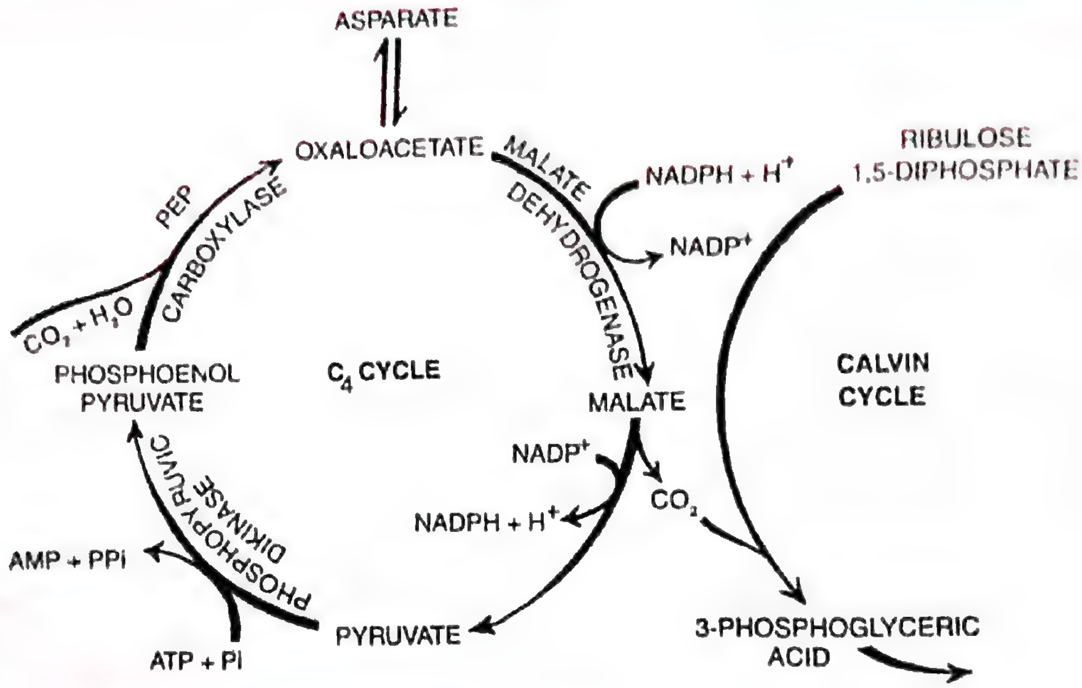


Fig. 13.6. Carbon dioxide fixation in C_4 dicarboxylic acid pathway.

Malic acid or aspartic acid is translocated to bundle sheath cells through plasmodesmata. Inside the bundle sheath cells they are decarboxylated (and deaminated in case of aspartic acid) to form pyruvate and CO_2 in the presence of malic enzyme.

CO_2 is again fixed inside the bundle sheath cells through Calvin cycle. RuBP of Calvin cycle is called **secondary** or **final acceptor** of CO_2 in C_4 plants. Pyruvate is sent back to mesophyll cells. Here, it is changed to phosphoenol pyruvate. Energy is required for this. The same is provided by ATP. The latter is changed into AMP (adenosine monophosphate).

$$\text{Pyruvate} + \text{ATP} + H_3PO_4 \xrightarrow{\text{Phosphopyruvate Dikinase}} \text{PEP} + \text{AMP} + \text{Ppi}$$

Conversion of AMP to ATP requires double the energy than energisation of ADP to ATP. The actual requirement of energy is equal to two molecules of ATP. This is in addition to 3 ATP required for fixation of one molecule of CO_2 through Calvin cycle. Therefore, C_4 plants consume 5 ATP molecules per molecule of CO_2 fixed instead of 3 ATP molecules for C_3 plants. For the formation of a glucose molecule, C_4 plants require 30 ATP while C_3 plants utilize only 18 ATP.

$$6\ PEP + 6RuBP + 6CO_2 + 30\ ATP + 12\ NADPH \longrightarrow 6\ PEP + 6\ RuBP + C_6H_{12}O_6 + 30\ ADP + 30\ H_3PO_4 + 12NADP^+$$

Importance. (i) C_4 plants have a disadvantage. They consume more energy (2 more ATP molecules per molecule of CO_2 fixed). However, sufficient energy is available in the tropics where the plants grow. Further, C_4 plants have little photorespiration. (ii) They are more efficient in picking up CO_2 even when it is found in low concentration because of the high affinity of PEP. (iii) They are able to trap CO_2 both from outside and that released internally due to respiration because of highly efficient PEP carboxylase. (iv) Effects of water stress are minimized in the C_4 plants as bundle sheath cells lie close to the source of water supply. (v) Because of their higher photosynthetic capacity and adaptability to adverse environmental conditions, some of the C_4 plants are serious weeds, *e.g.*, Amaranthus. (vi) Concentric arrangement of tissues provides a small surface area in relation to volume. This arrangement reduces transpiring surface and allows better utilization of available water. (vii) They can tolerate excess salts because of the presence of organic acids. (viii) Normal oxygen concentration is not inhibitory for the growth in contrast to C_3 plants. (ix) They are adapted to high temperature and intense radiation of tropics.

Differences between C_3 and C_4 Plants

C_3 Plants (Calvin Cycle)	*C_4 Plants (Hatch-Slack Cycle)*
1. Optimum temperature for photosynthesis is 10-25°C.	1. Optimum temperature is 30-45°C.
2. Atmospheric concentration of oxygen (21%) reduces the rate of photosynthesis which is optimum at 2-4%.	2. There is no such effect.
3. Saturation point is reached at 10-70% of full sunlight.	3. Saturation point is not reached even at full sunlight.
4. Rate of net photosynthesis at optimum sunlight is 15-35 mg $CO_2/dm^2/hr$.	4. Rate of net photosynthesis at full sunlight is 40-80 mg $CO_2/dm^2/hr$.
5. The leaves do not possess Kranz anatomy.	5. The leaves have Kranz anatomy.
6. Chloroplasts do not have peripheral reticulum.	6. Chloroplasts have peripheral reticulum.
7. Chloroplasts are of one type (monomorphic).	7. There are two types of chloroplasts (dimorphic).
8. Bundle sheath cells usually do not contain chloroplasts.	8. Bundle sheath cells contain chloroplasts.
9. RuBP is the first acceptor of CO_2.	9. PEP is the first acceptor of CO_2.
10. PGA is the first stable product.	10. Oxalo-acetic acid is the first product.
11. The plants operate only Calvin cycle.	11. Plants operate C_4 cycle in addition to Calvin Cycle.
12. CO_2 compensation point is 50-100 ppm.	12. CO_2 compensation point is 0-10 ppm.
13. Mesophyll cells perform complete photosynthesis.	13. Mesophyll cells perform only initial fixation.
14. The rate of carbon assimilation is slow.	14. The rate of carbon assimilation is quite rapid.
15. Rate of photorespiration is high.	15. Rate of photorespiration is negligible.
16. At low temperature, C_3 plants are more efficient while at high temperature their photosynthetic activity is comparatively reduced.	16. They are less efficient than C_2 plants at low temperature but are more efficient at high temperature.
17. The cycle operates in all plants.	17. The cycle is found only in some plants.

Crassulacean Acid Metabolism— CAM (The dark fixation of CO_2 in succulents).

Certain plants, especially succulents which grow under xeric conditions, fix atmospheric CO_2 in dark. These plants show diurnal pattern of organic acid formation *i.e.*, they accumulate organic acids in the leaves at night and decrease their production during the day. Since the process was first observed in the plants belonging to family crassulaceae, it was termed Crassulacean acid metabolism. Similar metabolism has been found to occur in other plants belonging to cactus, orchid and pineapple families. The CAM plants possess Xerophytic characters such as thick cuticle, sunken stomata and reduced leaves etc. The CAM is often divided into three phases:

Phase I (Acidification). In darkness, stored carbohydrates are converted to phosphoenol pyruvic acid by the process of glycolysis. The stomata are closed during the day and opened in dark which allows free diffusion of CO2 into the leaf. The phosphoenol pyruvic acid is carboxylated in the presence of enzyme PEP-Carboxylase.

$$\text{Phosphoenol pyruvic acid} + CO_2 + H_2O \xrightarrow{\text{PEP Carboxylase}} \text{Oxaloacetate}$$

$$\text{Oxaloacetate} + NADPH_2 \xrightarrow{\text{Malate dehydrogenase}} \text{Malate} + NADP^+$$

Malate is the end product of dark absorption of carbon dioxide. It is stored in the vacuoles.

Phase II (Deacidification) In the presence of light, organic acids move out of the vacuoles. Malic acid is decarboxylated to produce pyruvic acid and evolve carbon dioxide. This process is called deacidification. High temperature favours it. The reaction is usually carried out by malic enzyme, but in some plants it is catalysed by PEP carboxykinase.

$$\text{Malate} + NADP^+ \xrightarrow{\text{Malic enzyme}} \text{Pyruvate} + CO_2 + NADPH_2$$

$$\text{Pyruvate} + \text{ATP} + \text{Pi} \xrightarrow{\text{Phosphopyruvic Dikinase}} \text{PEP} + \text{AMP} + \text{PPi}$$

$$\text{Oxaloacetate} + \text{ATP} \xrightarrow{\text{PEP Carboxykinase}} \text{PEP} + \text{ADP} + CO_2$$

Phase III. The released carbon dioxide is picked up by ribulose biphosphate in the presence of RuBP carboxylase to perform Calvin cycle.

Significance of CAM. Both C_4 and CAM plants perform a similar type of photosynthesis. In both the cases, CO_2 is initially fixed by 3-carbon compounds to form 4-carbon dicarboxylic acids. These acids release CO_2 which is picked up by Calvin cycle. The CAM plants differ from C_4 plants in lacking bundle sheath cells. In CAM plants, there is separation of initial carboxylation and Calvin cycle in time (*i.e.,* day and night) instead of space in C_4 plants (*i.e.,* mesophyll and bundle sheath cells). CAM plants contain peroxisomes and perform photorespiration. CAM plants are usually succulent and their parts such as leaves, stems and petioles are fleshy or succulent.

Dark fixation of CO_2 has survival value for crassulacean plants. The stomata are kept closed during the day in order to conserve water which otherwise would be lost under extremely dry conditions.

At night, when the stomata are open, the CO_2 enters into the leaves and is fixed in the form of organic acids. During daytime, when stomata are closed, the acids release CO_2. The CAM plants refix CO_2 which is released in respiration whereas other plants lose it.

Cardinal Points. A factor influencing a physiological process has three principal values called cardinal points – **minimum, optimum and maximum.** The minimum is that value below which the process cannot continue. Maximum is that value beyond which the process comes to stop. Optimum value is that point where the physiological process can continue indefinitely at its highest velocity.

Principle or Law of Limiting Factors

Optimum value of a factor is never constant. It also depends upon the magnitude of other factors. We may continue to increase the magnitude of one or more factors without influencing the rate of reaction. In such cases it is found that a factor called limiting factor is holding the balance. *A limiting factor is* defined as *a factor which is deficient to such an extent that increase in its magnitude directly increases the rate of the process.* Blackmann formulated the **principle of limiting factors,** which states that when a *process is influenced by a number of factors, the rate of the process is limited by the pace of the slowest factor. Thus,* the rate of a physiological process is limited at a given time by only one factor which is deficient.

Blackmann studied the effect of CO_2 concentration, light intensity and temperature on rate of photosynthesis. All other factors were maintained in optimum concentration. Initially the photosynthetic material was kept at 20^0C in an environment having 0.01% CO_2. When no light was provided, there was no photosynthesis. Blackman provided light of low intensity and found photosynthesis to occur. When light intensity was increased, the rate of photosynthesis increased initially but soon it stopped increasing. The rate of photosynthesis could be further enhanced only on the increase in availability of CO_2. Thus, initially light intensity was limiting the rate of photosynthesis. When the same was available in sufficience, CO_2 became limiting. When both are provided in sufficient quantity, the rate of photosynthesis rose initially but could not be increased later on. At this time, it was found that increase in temperature could raise the rate of photosynthesis upto 35^0C. Further increase was not possible.

Objections. (i) Blackmann presumed that change over from one limiting factor to the other is abrupt. But transitional curves are present in change over regions. During transition, a change in either of the two factors may change the rate. The transitional curves are produced because of the presence of a large number of green cells and numerous chloroplasts in these cells. Some must be receiving more light than others while a few must be getting more CO_2. (ii) The rate cannot be increased indefinitely by increasing the availabity of all the known factors. (iii) The principle does not consider those factors, which cause inhibition of the process when present in excess.

Factors Influencing Photosynthesis

External Factors

1. **Carbon Dioxide.** CO_2 content of the atmosphere is 0.036% or 360 ppm or 360 %l/l. It is a limiting factor as the available CO_2 concentration is lower than the optimum for photosynthesis. Increase in its concentration upto at least 500ppm increases the rate of photosynthesis in C_3 plants. The C_4 plants attain saturation at much lower CO_2 concentration (around the present level of 360 ppm) than the C_3 plants. Photosynthesis is also influenced by the current increase in the atmospheric CO_2. It is expected that CO_2 concentration could reach to a level of about 600 ppm by 2020. **In such**

a case, the C_3 plants are likely to be benefited more than the C_4 plants. The fact that C_3 plants respond to higher CO_2 concentration by showing increased rates of photosynthesis leading to higher productivity has been used for some greenhouse crops such as tomatoes and bell pepper. They are allowed to grow in carbon dioxide enriched atmosphere that leads to higher yields. When CO_2 concentration is reduced, there comes a point at which illuminated plant parts stop absorbing carbon dioxide. It is known as CO_2 **compensation point** or **threshold value.** At this value CO_2 fixed in photosynthesis is equal to CO_2 evolved in respiration and photorespiration. The value is 50 – 100 ppm in C_3 plants and 0 – 10 ppm in C_4 plants. The reason for lower compensation point for C_4 plants is the greater efficiency of CO_2-fixation. The compensation point is generally higher in young leaves and plants. It also rises with the rise in temperature.

2. **Light Intensity.** Plants are classified into two groups depending upon their ability to tolerate high light intensity – **shade plants** (sciophytes, *e.g., Oxalis)* and **sun plants** (heliophytes, *e.g., Dalbergia)*. Shade plants are also known as heliophobuas and sun plants as heliophilous.

At low light intensity the rate of photosynthesis is reduced. There is a point in light intensity where there is no gaseous exchange in photosynthesis. It is called **light compensation point.** Its value is 2.5-100 ft candles for shade plants and 100-400 ft candles for sun plants. The light intensity at which a plant can achieve maximum amount of photosynthesis is called **saturation point.** Its value is 800-1000 ft candles (10% of full sunlight) in shade plants, 50-70% of full sunlight in C_3 sun plants and upto 200% of full sunlight in C_4 sun plants, (*e.g.,* Sugarcane). Saturation point is seldom realized in nature in C_4 sun plants. **Except for plants in shade or in dense forests, light is rarely a limiting factor in nature.**

Beyond saturation point photosynthesis begins to decline. The phenomenon is called **solarisation.** It is due to two reasons (i) **Photo-inhibition** due to reduction in hydration and closure of stomata. The reduction in hydration is due to increased rate of transpiration. (ii) **Photo-oxidation** or oxidation of photosynthetic pigments, intermediates and enzymes.

3. **Quality of Light.** Maximum photosynthesis occurs in blue violet and red regions of the light. Red light stimulates carbohydrate accumulation and blue light stimulates protein synthesis. Minimum photosynthesis occurs in the green light. Purple bacteria utilize both infra-red and ultra-violet light for photosynthesis. Higher plants do not use them. Rather, large and prolonged doses of UV-rays have harmful effects. Radiations emitted by fluorescent tubes suppress growth.

4. **Duration of Light.** Continuous photosynthesis can occur in continuous illumination without any harm to the plant. The rate may slightly decline after long periods of illumination, *e.g.* 40% decrease after six days in apple.

5. **Temperature. The dark reactions being enzymatic are temperature controlled. Though the light reactions are also temperature sensitive, they are affected to a much lesser extent.** The minimum temperature at which most plants start photosynthesis is 0° – 5°C but is as low as – 20°C for lichens and – 35°C for some gymnosperms. The maximum temperature at which it can occur is 55°C in some succulents and 75°C for thermal algae. The optimum temperature is 10° – 25°C for C_3 plants and 30^0 - 45°C in C_4 plants. When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in temperature. Above the optimum temperature, the rate of photosynthesis shows an initial increase for short duration but later declines. This decrease with time is called **time factor.** The possible causes of time factor can be: (i) Denaturation of enzymes and destructive effect on other protoplasmic constituents. (ii) Increased respiration and hence more consumption of photosynthates. (iii) Formation of secondary products, which may block some stage of photosynthesis. (iv) Affinity of enzyme Rubisco for CO_2 is also reduced at higher temperature.

The sensitivity of C_4 photosynthesis to low temperature, as compared to C_3 plants is due to the low temperature sensitivity of a particular enzyme (pyruvate phosphate dikinase) that is required in the C_4 pathway.

6. **Oxygen.** Small quantity of oxygen is essential for photosynthesis except in some anaerobic bacteria. C_3 plants show optimum photosynthesis at low oxygen concentration. The possible reasons are (i) Oxygen takes part in oxidation of photosynthetic pigments, intermediates and enzymes in the presence of strong light (photo-oxidation). (ii) Oxygen is a strong quencher of excited state of chlorophyll. (iii) Oxygen competes with CO_2 for reducing power produced during light reaction. However, this effect is not known in C_4 plants. (iv) It converts RuBP-carboxylase to RuBP-oxygenase and thus increases the rate of photorespiration. At a very high oxygen content the rate of photosynthesis begins to decline in all plants. The phenomenon is called **Warburg effect.**

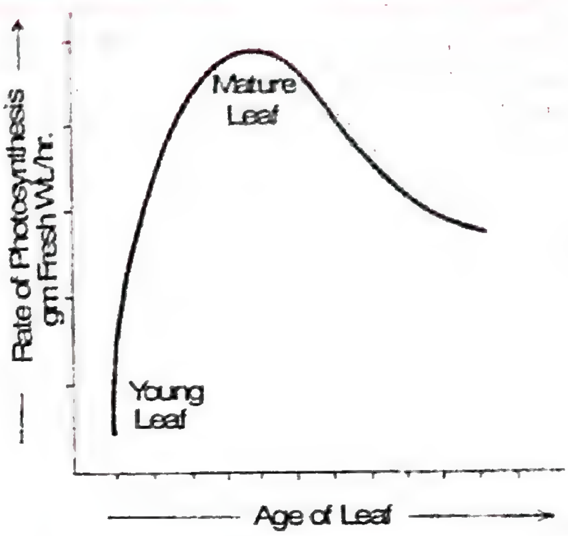


Fig. 13.7. Relation between age of leaf and rate of photosynthesis.

7. **Water. Even though water is one of the reactants in the light reaction, the effect of water as a factor is more through its effect on the plant, rather than directly on photosynthesis.** Less than 1% of the total water absorbed is utilized in photosynthesis. The rest is lost in transpiration. Even a slight increase in transpiration reduces the leaf hydration that decreases photosynthesis by causing stomatal closure and hence decreased CO_2 absorption, loss of leaf turgidity and leaf expansion which causes reduction in photosynthetic surface area, reduced absorption of solar radiations and decreased enzymatic activity. Photosynthesis is more sensitive to dehydration than any other metabolic process.

8. **Air Pollution.** Dust and smoke reduce photosynthesis by reducing light penetration. Sulphur dioxide, ozone, nitrogen oxides, hydrogen fluorides and other air pollutants also decrease photosynthesis.

9. **Minerals.** Magnesium is a component of chlorophyll. Fe, Cu and Mn are essential for synthesis of chlorophyll. Mn and Cl are linked to photolysis of water. Phosphate is required for ATP synthesis. Enzyme activators of photosynthesis include potassium and sulphur.

Internal Plant Factors

1. **Age.** Among various leaf factors, such as leaf age, leaf angle and leaf orientation, leaf age has the most prominent effect on photosynthesis. The rate of photosynthesis rises with the age of the leaf till it becomes maximum at full maturity. Afterwards the rate of photosynthesis begins to decline. The decrease is due to sluggishness of stomatal movement, lesser assimilation rate and decrease in other anabolic activities.

2. **Chlorophyll.** Photosynthesis does not occur in the absence of chlorophyll. But there is no proportionality between the rate of photosynthesis and amount of chlorophyll. For example, sun plants contain less chlorophyll as compared to shade plants but the rate of photosynthesis in bright light is much higher in sun plants than in shade plants.

3. **Hormones.** Cytokinins and gibberellins increase the rate of photosynthesis while abscisic acid reduces it.

4. **Leaf anatomy.** It influences the rate of diffusion of CO_2 into the chlorenchyma cells, availability of light, rate of translocation of end products etc. The anatomical structures influencing them are size, structure, position and frequency of stomata, thickness of epidermis and cuticle, distribution and number of vascular strands, size and distribution of intercellular spaces, etc.

5. **Accumulation of end products.** Slow rate of translocation causes accumulation of photosynthetic end products during afternoon. It decreases the rate of photosynthesis.

6. **Carotenoids.** They are essential to prevent photo-oxidation which reduces photosynthesis.

7. **Endogenous rhythm.** Many plants show maximum photosynthesis at a particular time of the day and a specific season of the year, *e.g.*, dinoflagellate Gonyulax has maximum photosynthetic activity near noon. The rhythm becomes weaker under constant environmental conditions.

MULTIPLE CHOICE QUESTIONS

1. In the 1930s C.B. van Niel correctly hypothesized that oxygen atoms in the oxygen gas released by plants come from
(1) H_2O (2) CO_2
(3) $C_6H_{12}O_6$ (4) O_3

2. One of the earliest experiments on photosynthesis was done in 1770 by Joseph Priestley. He demonstrated that
(1) sunlight is the energy source
(2) water is required
(3) plants and animals "restore" the air for each other
(4) chlorophyll captures light energy

3. Maximum absoption of light occurs in the region (PAR) of
(1) 400 –700 nm (2) 700 – 900 nm
(3) 1000 – 1200 nm
(4) 1500 – 2000 nm

4. Photosynthesis, a process of manufacture of organic compounds is
(1) catabolic exothermic, reductive process
(2) anabolic endothermic, oxidative reductive process
(3) both anabolic and catabolic process
(4) a chemical process

*5. What is the common value of PQ (Photosynthetic quotient) of a leaf ?
(1) > 1 (2) < 1 (3) 1 (4) 0

6. Which is the most effective wave length of light for photosynthesis ?
(1) Green (2) UV light
(3) Red (4) Yellow

7. Hydrogen for the synthesis of organic compounds in photosynthesis comes from
(1) $NADH_2$ (2) $FADH_2O$
(3) H_2O (4) CO_2

8. The correct summary of photosynthesis is
(1) $6CO_2 + 6H_2O + \text{light} \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$
(2) $6CO_2 + 12H_2O + \text{light} \longrightarrow C_6H_{12}O_6 + 6O_2 \uparrow + 6H_2O$
(3) $C_6H_{12}O_6 + 6O_2 + 6H_2O + \text{light} \longrightarrow 6CO_2 \uparrow + 12H_2O$
(4) $6CO_2 + 6H_2O + \text{light} \longrightarrow C_6H_{12}O_6 + 3O_2 \uparrow + 6H_2O$

9. It is advantageous to use *Hydrilla* to demonstrate photosynthesis than land plants as
(1) it respires slowly
(2) it does not transpire
(3) it photosynthesizes rapidly
(4) oxygen bubbles can be collected over water

10. Which of the following is least effective in photosynthesis
(1) sunlight (2) red light
(3) blue light (4) green light

*11. Photosynthesis is the fastest in
(1) Blue light
(2) Intermittent white light
(3) Red light (4) Green light

12. Both respiration and photosynthesis require
(1) sunlight (2) green cells
(3) cytochromes (4) organic substrate

13. A photosynthetic organism which does not release oxygen is
(1) blue green alga
(2) green sulphur bacterium
(3) green alga
(4) algal component of lichen

14. What is true for photosynthesis ?
(1) Both carbon dioxide and water are oxidised
(2) Both carbon dioxide and water are reduced
(3) Carbon dioxide is oxidised and water reduced
(4) Carbon dioxide is reduced and water oxidised

15. Who was the first to explain the evolution of oxygen during photosynthesis
(1) Dutrochet (2) Joseph Priestley
(3) V. Holmont (4) Wilstatter

*5. $PQ = \frac{O_2}{CO_2} = \frac{6O_2}{6CO_2} = 1$

... product formed in light reaction is consumed in dark reaction.

16. The role of water in photosynthesis was experimentally confirmed by
(1) T.D. Saussure (2) Barnes
(3) Liebig (4) J.R. Mayer

*17. Who **proved** that oxygen evolved in photosynthesis comes from water ?
(1) Mayer
(2) Calvin
(3) Ruben and Kamen
(4) Emerron

18. Which technique has helped in investigation of Calvin cycle ?
(1) X-ray cyrstallography
(2) X-ray technique
(3) Radioactive isotope (autoradiography) technique
(4) Intermittent light

19. Radioactive isotopes employed to study photosynthesis are
(1) ^{11}C and ^{32}P (2) ^{15}C and ^{32}P
(3) ^{16}C and ^{15}N (4) ^{14}C and ^{18}O

20. The first step in photosynthesis is the
(1) formation of ATP
(2) ionization of water
(3) excitation of chlorophyll by photon of light
(4) attachment of CO_2 to carbon sugar

21. During photosynthesis oxygen in glucose comes from
(1) water (2) carbon dioxide
(3) both (1) and (2) (4) oxygen in air

22. Dark reaction/Calvin cycle of photosynthesis occurs in
(1) grana of chloroplast
(2) stroma of chloroplast
(3) matrix of mitochondrion
(4) cytoplasm

23. Moll's half leaf experiment shows
(1) unequal transpiration from two surfaces of leaf
(2) CO_2 is essential for photosynthesis
(3) relation between transpiration and absorption
(4) chlorphyll is essential for photosynthesis

24. Where does the primary photo-chemical reaction occur in chloroplast ?
(1) Stroma (2) Periplast cavity
(3) Quantosomes
(4) Inner membrane of chloroplast

25. One of the following pigments does not occur in chloroplast.
(1) Chlorophyll (2) Carotene
(3) Anthocyanin (4) Xanthophyll

26. Which colour of light gives maximum absorption peak of chlorophyll *a*
(1) Red (2) Blue
(3) Green (4) Yellow

27. Algae often float on the surface of water during day but sink down during night due to
(1) evolution and trapping of oxygen bubbles during day in their photosynthesis
(2) becoming light as they consume most of their food in the night
(3) warming action of sun during the day
(4) release of absorbed air by warming of water

28. Thylakoids removed from chloroplasts were kept in illuminated culture having CO_2 and water, it did not produce sugar because of
(1) absence of enzymes
(2) non linking of PS I and PS II
(3) absence of light trapping molecules
(4) non formation of assimilatory power

29. The evidence that during photosynthesis oxygen comes from water is
(1) photosynthetic bacteria employ H_2S and CO_2 to form carbohydrates, water and sulphur
(2) isolated illuminated chloroplasts release oxygen if provided with potassium ferrocyanide
(3) isotopic ^{18}O provided as $H_2{}^{18}O$ appears as $^{18}O_2$ liberated in photosynthesis
(4) all the above

30. When the rate of translocation is slow, the rate of photosynthesis shall
(1) increase (2) decrease
(3) remain unchanged (4) become zero

31. Aerobic bacteria collect near illuminated phytoplankton due to
(1) Manufactured food (2) Light
(3) Oxygen
(4) Reduced CO_2 concentration

*17. Hill demonstrated that O_2 comes from H_2O. It was proved experimentally by Ruben and Kaman using labelled O_2 as H_2O^{18}.

32. Maximum O_2 evolution occurs from
(1) forests
(2) marine phytoplankton
(3) crops
(4) land mass

33. Photo oxidation of water (in photosynthesis) occurs in association of
(1) Cytochrome B_6 (2) Plastocyanin
(3) PS II (4) PS I

34. The law of limiting factors for photosynthesis was enunciated by
(1) R. Hill (2) Calvin
(3) Krebs (4) Blackman

35. The enzyme that catalyses initial carbon dioxide fixation in C_4 plants is
(1) RuBP carboxylase (RUBISCO)
(2) PEP carboxylase (PePCO)
(3) Carbonic anhydrase
(4) Carboxy dismutase

36. The first stable compound in C_4 plants is
(1) malic acid
(2) oxalo acetic acid
(3) phosphogylceric acid
(4) aspartic acid

*37. C_4 plants can absorb CO_2 from
(1) its much low concentration
(2) much high concentration
(3) carbonates
(4) bicarbonates

38. In C_4 pathway, initial carbon dioxide fixation occurs in chloroplasts of
(1) guard cells (2) mesophyll
(3) bundle sheath (4) all of these

39. In C_4 plants, Calvin cycle operates in
(1) stroma of bundle sheath chloroplasts
(2) grana of bundle sheath chloroplasts
(3) grana of mesophyll chloroplasts
(4) stroma of mesophyll chloroplasts

40. Carotenoids
(1) do not take any part in photosynthesis
(2) also absorb light energy and transfer it to chlorophyll
(3) absorb only heat energy
(4) only help to colour the young leaves and pericarps

41. A chlorophyll molecule has the magnesium located in the
(1) phytol chamber
(2) centre of porphyrin
(3) corner of porphyrin (4) isocyclic ring

42. The common xanthophyll occurring in leaves is
(1) lutein (2) β-carotene
(3) fucoxanthin (4) Bacterioviridin

43. Carotenes absorb ________ light and transmit ________ and hence are orange in colour
(1) blue and green, orange and red
(2) Red and yellow, blue and green
(3) blue and red, orange and yellow
(4) green and yellow, blue and red

44. The emperical formula/structure for chlorophyll *a* is
(1) $C_{35} H_{72} O_5 N_4 Mg$
(2) $C_{65} H_{70} O_6 N_4 Mg$
(3) $C_{55} H_{72} O_5 N_4 Mg$
(4) $C_{45} H_{70} O_6 N_4 Mg$

45. Pigment system is concerned with
(1) reduction of CO_2 (2) flowering
(3) photolysis of water (4) none

46. Chlorophyll *b* is
(1) $C_{54} H_{70} O_6 N_4 Mg$
(2) $C_{55} H_{70} O_6 N_4 Mg$
(3) $C_{55} H_{72} O_5 N_4 Mg$
(4) $C_{45} H_{72} O_5 N_4 Mg$

47. Chlorophyll *a* occurs in
(1) all photosynthetic autotrophs
(2) in all higher plants
(3) all oxygen liberating autotrophs
(4) all plants except fungi

48. Emerson effect shows the existence of
(1) photorespiration
(2) photophosphorylation
(3) light and dark reactions
(4) two ditinct photochemical reactions

49. Which is the first stable intermediate of photosynthesis
(1) glucose (2) formaldehyde
(3) phosphoglyceric acid
(4) phosphoglyceraldehyde

*37. The enzyme PEP-carboxydismutase present in C_4 plants is very sensitive to CO_2 this is why the C_4 plants can absorb CO_2 even from its much low concentration while the C_3 plants fail to avail it from such low concentration.

50. Flow of electrons in non-cyclic photophosphorylation is
(1) from PS I to PS II
(2) bidirectional
(3) unidirectional (4) both (2) and (3)

51. Photolysis of water results in the release of
(1) electrons, protons (H^+) and oxygen
(2) electrons and protons (H^+)
(3) protons (H^+) and oxygen
(4) electrons and oxygen

52. ATP in non-cyclic photophosphorlyation is formed when electron passes from
(1) plastocyanin to P_{700}
(2) plastoquinone to ferrodoxin
(3) cytochrome *f* to plastoquinone
(4) cytochrome *b* to cytochrome *f*

53. Cyclic photophosphorylation operates absorbing light of
(1) more than 680 μm wavelength
(2) less than 680 μm wavelength
(3) less than 660 μm wavelength
(4) wavelength between 660–680 μm wavelength

54. During light reaction of photosynthesis, which of the following phenomena is observed during cyclic and non-cyclic photophosphorylation ?
(1) Formation of ATP
(2) Formation of $NADH_2$
(3) Release of O_2
(4) Involvement of PS I and PS II both

55. How many full turns of the Calvin cycle are required to make one molecule of glucose
(1) one (2) two (3) four (4) six

56. In a controlled experiment of photosynthesis, CO_2 supply is suddenly withheld, which of the following will accumulate in the plant cell?
(1) 3-phosphoglyceraldehyde
(2) Ribulose diphosphate
(3) glucose
(4) phosphoglyceric acid

57. Through which of the following substances the photosystem I passes an electron to NADP during light reactions ?
(1) Cytochrome (2) Ferrodoxim
(3) Plastocyanin (4) Plastoquinone

58. In cyclic photophosphorylation, ATP is synthesized when electron passes from
(1) ferredoxin to cytochrome b_6
(2) plastoquinone to cytochorme *f*
(3) ferredoxin to plastoquinone and cytochrome b_6 to cytochrome *f*
(4) all the above are wrong

59. In pigment system II, reaction centre is
(1) P_{680} (2) P_{830} (3) P_{700} (4) P_{673}

60. Which of the following best constitutes Hill reaction ?
(1) Photolysis by chloroplasts
(2) Photolysis of water by isolated chloroplasts forming ATP and NADPH
(3) Photolysis of water by isolated illuminated chloroplasts causing reduction of some chemicals and liberation of oxygen
(4) Photolysis of water liberating oxygen and hydrogen by illuminated isolated chloroplasts

61. The organism/s used in discovering Calvin's cycle was/were
(1) *Chlorella*
(2) *Chlorella* and *Volvox*
(3) *Chlorella* and *Chlamydomonas*
(4) *Chlorella* and *Scenedesmus*

62. Which of the following occurs during dark phase of photosynthesis ?
(1) Hydrogen is released
(2) ATP is produced
(3) Molecular oxygen is released
(4) PGAL is synthesized

*63. If an angiosperm is kept at compensation point
(1) it will die after some time
(2) it's growth will be normal
(3) its growth will be faster
(4) its growth will stop, but it will not die

64. During dark reaction for fixation of Carbon, the three carbon atoms of each molecule of 3–PGA are derived from
(1) RuBP only (2) RuBP + CO_2
(3) CO_2 only (4) RuBP + CO_2 + PEP

65. The first stable product of CAM cycle is
(1) Oxalic acid (2) Malic acid
(3) Oxalo-acetic acid (4) Pyruvic acid

*63. At compensation point, the rate of photosynthesis will be equal to the rate of respiration.

66. The CO_2 stored by succulents during night is used during the day time in
(1) Hatch & Slack pathway
(2) Calvin cycle
(3) CAM (4) TCA Cycle

67. Deactivation of enzymes above 40°C affects the ________ of photosynthesis and decreases the rate of photosynthesis
(1) light reaction (2) dark reaction
(3) photolysis of water
(4) excitation of chlorophyll

68. Rate of photosynthesis is ________ than that of respiration during the day time
(1) higher (2) lower
(3) same (4) equal

69. During photosynthesis when PGA is changed into phosphoglyceraldehyde, which of the following reactions occur ?
(1) Oxidation (2) Reduction
(3) Electrolysis (4) Hydrolysis

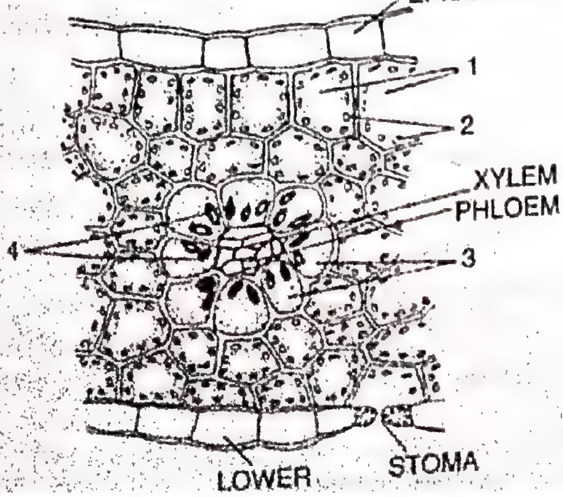
70. Which products of Hill reaction are used in Blackman's reaction
(1) ATP, NADPH (2) ATP, NADH
(3) ADP, NAD (4) ATP, NAD

71. Acid concentration in CAM plants is more at
(1) night (2) daytime
(3) dawn (4) dusk

72. In PS-II, first known electron acceptor is
(1) Cytochrome (2) Quinone
(3) FRS (4) Ferredoxin

73. For synthesis of a molecule of glucose in C_4 plant the requirement of ATP and NADPH is respectively
(1) 15 and 10 (2) 33 and 22
(3) 12 and 8 (4) 30 and 12

74. The given diagram is a cross section



(1) of a leaf
(2) showing Kranz anatomy
(3) dimorphic chloroplast
(4) all of the above

75. In photorespiration, RuBP carboxylase combines with oxygen to yield
(1) Two molecules of phosphoglycerate
(2) Two molecules of phosphoglycolate
(3) One molecule of phosphoglycerate and one molecule of phosphoglycolate
(4) Two molecules of glucose

76. C_4 plants are abundant in
(1) temperate region with more humid conditions
(2) temperate region with more dry conditions
(3) tropical region with more humid conditions
(4) tropical region with more dry conditions

77. What is correct about Dark Reaction ?
(1) It is called Hill reaction
(2) It is biochemical, enzymatic, rate determining slow reaction
(3) It is independent of temperature
(4) All of these

78. Choose the correct one for photorespiration that occurs in C_3 plants.
(1) Photorespiration is common in plants having high CO_2 compensation point
(2) Photorespiration is caused by high CO_2 and low O_2
(3) It is not affected by light, temperature
(4) all of the above

79. Positive effect of photorespiration
(1) reduces O_2 injury to chloroplast in C_3 plant
(2) balance the O_2/CO_2 ratio of plant
(3) increase the yield of plant
(4) donot have any positive effect

80. Photorespiration is also known as
(1) C_2 cycle (2) C_3 cycle
(3) C_4 cycle (4) C_1 cyle

81. Emerson found red drop in the wavelength
(1) 660 nm (2) 670 nm
(3) < 680 nm (4) > 680 nm

82. Cardinal value of temperature refers to
(1) minimum temperature
(2) maximum temperature

(3) minimum, maximum and optimum temperature
(4) minimum and maximum temperature

83. How much assimilatory power is produced per molecule of oxygen produced in light reaction ?
(1) 2ATP + 1 $NADPH_2$
(2) 2ATP + 2 $NADPH_2$
(3) 1ATP + 1 $NADPH_2$
(4) 1 ATP + 2 $NADPH_2$

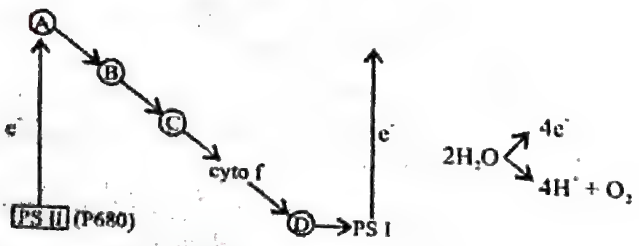
84. Dicarboxylic acid cycle is also known as
(1) Calvin cycle (2) Hatch & Slack cycle
(3) EMP cycle (4) TCA cycle

85. The first reaction in photorespiration is
(1) phosphorylation
(2) decarboxylation
(3) oxygenation
(4) carboxylation

86. During photorespiration, the oxygen consuming reaction(s) occur in
(1) grana of chloroplasts and peroxisomes
(2) stroma of chloroplasts
(3) stroma of chloroplasts and mitochondria
(4) stroma of chloroplasts and peroxisomes

87. In photorespiration, where CO_2 is released ?
(1) Mitochondria (2) Chloroplast
(3) Peroxisome (4) Vacuole

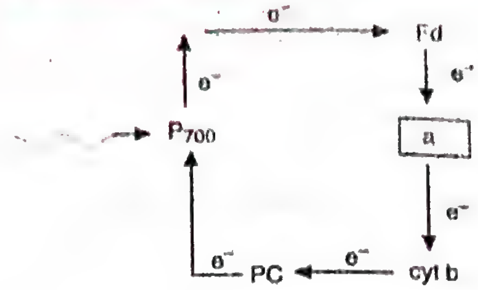
88. In the schematic diagram given, which is plastocyanin ?



(1) A (2) B (3) C (4) D

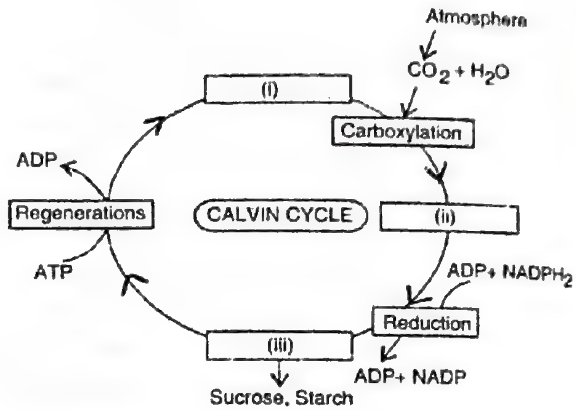
89. NH_3 is released during
(1) photorespiration
(2) dark respiration
(3) CAM
(4) all of these

90. In the chart of photophosphorylation, what does 'a' represent



(1) Cyt a (2) PQ
(3) FRS (4) Cyt a_3

91. Choose the correct combinations of labelling the carbohydrate molecule involved in the Calvin cycle.



(1) (i) RuBP (ii) Triose phosphate (iii) PGA
(2) (i) PGA (ii) RuBP (iii) Hexose phosphate
(3) (i) PGA (ii) Triose Phosphate (iii) RuBP
(4) (i) RuBP (ii) PGA (iii) Hexose phosphate
(5) (i) Triose phosphate (ii) PGA (iii) RuBP

92. When sunlight is on the chloroplast, *p*H is lowest in the
(1) Stroma (2) Cytosal
(3) Space enclosed by thylakoid membrane
(4) Space enclosed by the inner and outer membrane

93. $NADPH_2$ is generated in noncyclic photophosphorylation through
(1) glycolysis (2) photosystem I
(3) photosystem II
(4) anaerobic respiration

*94. Warburg effect has not been observed in
(1) Maize (2) Sugarcane
(3) *Sorghum* (4) All of these

95. In C_4 cycle, first CO_2 acceptor is
(1) 3C compound (2) 4C compound
(3) 5C compound (4) 6C compound

*94. Warbug effect is the reduction in photosynthesis in high conc. of O_2. It is almost absent in C_4 plants.

96. Chlorophyll shows an outburst of fluorescence during the first few moments of illumination. This effect is called
(1) Emerson's effect
(2) Kutusky effect
(3) Hamburger effect
(4) Hill effect

97. Photophosphorylation in chloroplast is most similar to which of the following mitochondrial reactions ?
(1) Oxidative phosphorylation
(2) Substrate-level phosphorylation
(3) Oxidative decarboxylation
(4) Hydrolysis

98. In an experiment, the carbon dioxide available to a C_3 plant was labelled with a radioactive isotope and the amount of radioactivity in the chloroplast was measured. As photosynthesis proceeded, in which of the following molecules did the radioactivity first appear ?
(1) PGAL (2) PEP
(3) PGA (4) RuBP

99. Which of the following kinds of plant fixes carbon dioxide by way of crassulacean acid metabolism (CAM)
(1) Oak tree (2) Cactus
(3) Grass (4) Red alga

100. Chemiosmotic theory of ATP synthesis in chloroplast & mitochondria is based on
(1) membrane potential
(2) proton gradient
(3) accumulate of Na^+
(4) accumulation of K^+

101. A photosystem contains
(1) pigments, electron acceptor & a reaction centre
(2) photons, protons, pigments & hydrogen acceptor
(3) PO_4, ADP & H^+
(4) (1) & (2) both

102. Which pair is wrong ?
(1) C_3 – Maize
(2) C_4 – Kranz anatomy
(3) Calvin cycle – PGA
(4) Hatch & Slack cycle - OAA

103. Choose the correct statement for the fixation of one CO_2 molecule
(1) 3 ATP & 2 NADPH are required through calvin cycle
(2) 5 ATP & 2 NADPH are required through Hatch & slack cycle
(3) Photochemical reactions are involved in photolysis of water & phosphorylation of ADP into ATP
(4) all of the above

104. During non-cyclic photophosphorylation ATP molecules are produced through electron flow
(1) from H_2O to PS II
(2) from PS II to PS I
(3) from PSI to NADP
(4) from PSI to ferredoxine

105. Emerson effect is related to
(1) decrease in photsynthesis in presence of high light intensity
(2) decrease in photosynthesis when lights of two different wavelengths are provided together
(3) increase in photosynthesis in presence of monochromatic light
(4) increase in photosynthesis when lights of two different wavelengths are used

106. Radioactive isotope of oxygen (O^{18}) was used to know the source of oxygen released through photosynthesis by
(1) Hill (2) Van Neil
(3) Ruben and Kamen
(4) Hatch and Slack

107. Which of the following photosynthetic characteristics are present in C_3 plants but not in C_4 plants ?
I. CO_2 compensation point of 0–10 ppm
II. Relatively higher rate of Photorespiratory CO_2 evolution
III. Presence of well developed bundle sheath
IV. Initial involvement of RUBP carboxylase in CO_2 assimilation

Select the correct answer using the codes given below
(1) I, II, III (2) I, II, IV
(3) I, III (4) II, IV

108. The following compounds are intermediates in the pathway of photorespiration
I. phosphoglycolate II. serine
III. glyoxylate IV. glycine

The correct sequence of their appearance in the pathway is

(1) I, II, III, IV (2) I, III, IV, II
(3) II, I, III, IV (4) II, I, IV, III

109. Number of carboxylations in C_4 plant is
(1) four (2) three (3) two (4) one

110. Inhibition of photosynthesis in high concentration of oxygen is mainly due to
(1) distribution of RuBP carboxylase
(2) inactivation of RuBP carboxylase
(3) non-synthesis of RuBP carboxylase
(4) RuBP carboxylase acting as oxygenase

111. During light reaction of photosynthesis the electrons lost by pigment system II are compensated by
(1) CO_2 (2) H_2O (3) O_2 (4) ATP

112. Which of the following is essentially regenerated to complete the Calvin Cycle
(1) PGA (2) RUBP
(3) PEP (4) OAA

113. During photorespiration glycolic acid is oxidised to glyoxylic acid inside
(1) chloroplast (2) peroxysome
(3) motochondria (4) lysosome

114. C_4 plants are more expensive in terms of ATP required for CO_2 fixation, the additional number of ATP required by C_4 plants in comparison to C_3 plants is
(1) 6 ATP (2) 12 ATP
(3) 18 ATP (4) 24 ATP

*115. The plant of *Cuscuta reflexa* (Dodder) shows maximum photosynthesis in
(1) red light (2) blue light
(3) green light
(4) No photosynthesis at all

116. Hatch-Slack pathway
(1) has chloroplasts of same type
(2) occurs in Kranz anatomy where mesophyll cells have small granal chloroplast and bundle sheath cells have agranal chloroplast
(3) occurs in Kranz anatomy when mesophyll have small chloroplast whereas bundle sheath have larger granal chloroplasts
(4) occurs in Kranz anatomy where mesophyll cells are diffused

117. Which of the statements is not true for C_4 pathway ?
(1) Overcomes loss due to photorespiration
(2) The CO_2 acceptor is a C_3 compound
(3) Inhibited by low CO_2 concentration
(4) Required more energy than the C_3 pathways for production of glucose

118. Which of the following conditions are favourable for cyclic photophosphorylation ?
(1) Anaerobic condition and high CO_2
(2) Aerobic and high CO_2
(3) Aerobic and low light intensity
(4) Anaerobic and low light intensity

119. The light reactions of photosysntheysis generate high energy electrons, which end up in ________. The light reactions also produce ________ and ________.
(1) oxygen, sugar, ATP
(2) chlorophyll, ATP, NADPH
(3) NADPH, ATP, Oxygen
(4) FADH, NADPH, oxygen

120. Secondary acceptor of CO_2 in C_4 plants is
(1) PEP (2) RUBP
(3) PGAL (4) Rubisco

121. Which one of the following phenomena is represented by Calvin Cycle ?
(1) Oxidative carboxylation
(2) Dark phosphorylation
(3) Dark respiration
(4) Reductive carboxylation

122. Isolated chloroplasts release oxygen when illuminated. Supply of which of the following will increase the rate of oxygen production ?
(1) $NADP^+$ (2) NAD^+
(3) FAD^+ (4) ATP

123. *Solarisation* is
(1) formation of chlorophyll
(2) effect of excess solar radiation
(3) Destruction of chlorophyll by poisons
(4) utilisation of sunlight

124. There is double fixation of CO_2 both in C_4 and CAM plants. Which of the following statements brings out the main difference between the two ?
(1) Carboxylising enzymes are different
(2) Fixation pathways are different
(3) CO_2 fixation in C_4 plants is separated

*115. *Cuscuta* is non green stem parasite.

by space whereas in CAM plants, it is separated by time

(4) The compensation point are different

125. Primary electron acceptor in cyclic photophosphorylation is

(1) Rubisco (2) $NADP^+$

(3) FAD

(4) Iron — Sulphur containing protein (FeS)

126. Source of CO_2 for photosynthesis during day in CAM plants is

(1) 3 DGA (2) Malic acid

(3) OAA (4) Pyruvate

127. CO_2 fixation in bundle sheath cells occur in

(1) C_4 Plants (2) C_3 Plants

(3) CAM (4) all of these

128. Match the sites in column I with the process in column II and choose the correct combination

Column I	Column II
A Grana of chloroplast	I Krebs cycle
B Stroma of chloroplast	II Light reaction
C Cytoplasm	III Dark Reaction
D Mitochondrial matrix	IV Glycolysis

(1) A-II B-III C-IV D-I

(2) A-I B-II C-III D-IV

(3) A-II B-III C-I D-IV

(4) A-I B-III C-II D-IV

*129. How much O_2 is formed from 264 g CO_2 & 216 g of H_2O

(1) 96 g (2) 216 g (3) 264 g (4) 192 g

130. With reference to photosynthesis, what is the $CF_0 - CF_1$ complex?

(1) ATP synthetase*

(2) Ferredoxin – NADP reductase

(3) Cytochrome b_6/ $f$complex

(4) RuBP carboxylase

131. Which set of terms most accurately describes the pathway taken by a molecule of CO_2 from the atmosphere to the point where it enters the calvin cycle ?

(1) stomatal aperture, inter cellular space, mesophyll cell, chloroplast

(2) stomatal aperture, epidermal cell, mesophyll cell, chloroplast

(3) stomatal guard cell, intercellular space, mesophyll cell membrane, chloroplast

(4) stomatal guard cell, intercellular space, phloem serve tube, chloroplast

132. During non-cyclic photophosphorylation, in which of the following, $4e^-$ produced through photolysis of water will enter ?

(1) PQ (2) PC

(3) PS-II (4) PS-I

133. The number of P_{700} molecules present in PS II complex are

(1) one (2) two

(3) three (4) none

134. Red colour of tomato is due to

(1) phytochrome (2) anthocyanin

(3) chromatochrome (4) lycopene

135. Quantasomes are found in

(1) stroma (2) grana

(3) mitochondria (4) cristae

136. In the leaves of C_4 plants, malic acid formation during CO_2 fixation occurs in the cells of

(1) Phloem (2) Epidermis

(3) Mesophyll (4) Bundle Sheath

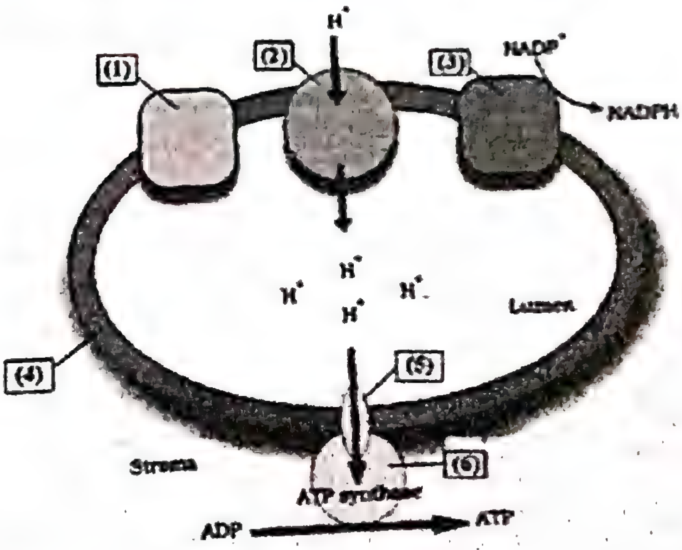
137. 3-PGA is first stable product in

(1) carbon-reduction cycle

(2) CAM

(3) Glycolysis (4) Kreb's cycle

138. Go through the following figure and select the option which reflects the correct labelling



(1) Photosystem II; (2) Cytochromes b & f;

*129. $6CO_2 + 12H_2O \longrightarrow 6O_2 + C_6H_{12}O_6$
(264 kg) (192 kg)

(3) Photosystem I; (4) Thylakoid membrane; (5) Fo; (6) F_1

(2) Photosystem I; (2) Cytochromes b & f; (3) Photosystem II; (4) Thylakoid membrane; (5) Fo; (6) F_1

(3) Photosystem II; (2) Cytochromes b & f; (3) Photosystem I; (4) Thylakoid membrane; (5) F_1; (6) Fo

(4) Cytochromes b & f; (2) Photosystem I; (3) Photosystem II; (4) Chloroplast membrane; (5) F_O; (6) F_1.

139. Given below are some characteristics of photosynthetic plants. Which of these are true for C_4 plants

(i) Rubisco is present in the mesophyll cells

(ii) 3-carbons in the primary CO_2 acceptor

(iii) The primary CO_2 fixation product is PGA

(iv) Possess PEP Case.

(v) The initial carboxylation reaction occurs in bundle sheath cells

(vi) The calvin cycle takes place in bundle sheath cells

(vii) 4-carbon atoms in the primary CO_2 fixation product.

(1) (i), (iv), (v), (vii)
(2) (i), (ii), (iii), (iv), (vii)
(3) (ii), (iii), (iv), (vi), (vii)
(4) (ii), (iv), (vi), (vii)

*140. RuBP carboxylase is a less efficient enzyme for CO_2 fixation in photosynthesis than PEP carboxylase because:

(1) RuBP is less predominant than PEP in a mesophyll cell

(2) RuBP is a 4-carbon sugar phosphate while PEP is a phosphorylated 3-carbon organic acid.

(3) Km value of RuBP carboxylase for CO_2 is higher than that of PEP carboxylase*

(4) The molecular weight of RuBP carboxylase is larger than that of PEP carboxylase

141. Consider the following processes:

1. O_2 evolution 2. CO_2 fixation
3. NADPH formation 4. HMP pathway

Which of these do not occur in thylakoids?

(1) 1, 2 and 4 (2) 2, 3 and 4
(2) 3 and 4 (4) 2 and 4

142. Consider the following compounds:

1. Phosphoenol pyruvate
2. Malic acid
3. Pyruvic acid 4. Oxaloacetic acid

What is the correct sequence of these intermediate compounds as they form in C_4 dicarboxylic acid pathway flowing the PEP-carboxylation reaction?

(1) 1, 2, 3, 4 (2) 2, 4, 3, 1
(3) 4, 1, 2, 3 (4) 4, 2, 3, 1

143. An aquatic plant was placed in a test tube containing water. The tube was then stoppered and left outdoors for 24 hours. The *p*H value of water was measured at regular intervals. What must have been the result?

(1) *p*H value was the lowest just before sunrise

(2) *p*H value was the highest just before sunrise

(3) *p*H value was the lowest at noon

(4) *p*H value was the lowest just before sun set

144. Compared to C_3 plants, C_4 plants

(1) Remove oxygen from the air spaces between cells in the leaves and thereby avoid photorespiration

(2) Fix carbon dioxide into a four carbon sugar at night, and then release the carbon dioxide during the day

(3) Concentrate oxygen in cells, thereby overcoming the problem of photorespiration

(4) Have adaptations which concentrate carbon dioxide in the photosynthetic cells

145. Which statement best explains why C_4 grasses often do better than C_3 grasses in hot dry environments?

(1) C_4 grasses open their stomata at night

(2) C_4 grasses have nearly eliminated photorespiration

(3) C_4 grasses generate a positive turgor pressure under high temperatures

(4) The rate of cellular respiration is higher for a C_3 grass than for a C_4 grass at higher temperatures

146. Differences between photophosphorylation (PP) and oxidative phosphorylation (OP) is

*140. RuBP carboxylase is a very slow enzyme, fixing only three molecules of its substrate every second and hence a large amount of this enzyme is needed by each plant. Typically, RuBP carboxylase accounts for 50% or so of the total protein in a chloroplast.

(1) In PP, synthesis is of ATP while in OP it is of ADP
(2) In PP, oxygen is evolved while in OP oxygen is taken up
(3) Both cannot take place in light
(4) PP can take place in green leaves while OP cannot occur in green leaves

147. Hill reaction occurs in
(1) High altitude plants
(2) Total darkness
(3) Absence of water
(4) Presence of ferricyanide

148. Photosynthetic oxygen-producing cells differ from non-oxygen producing cells in that the former
(1) Produce three ATP whereas the latter produce five
(2) Produce no NADPH whereas the latter do
(3) Reduce ferredoxin whereas the latter do not
(4) Contain and use both photosystems I and II

In each of the following questions, a statement of ASSERTION [A] is given followed by a corresponding statement of REASON [R] just below it. Of the statements, mark the correct answer as —
(1) *If both A and R are true and R is the correct explanation of A*
(2) *If both A and R are true but R is not the correct explanation of A*
(3) *If A is true but R is false*
(4) *If both A and R are false*

*149. **Assertion:** C_4 photosynthesis is more sensitive to low temperature as compared to C_3 photosynthesis.

Reason: The Rubisco found in C_4 plants is more sensitive to low temperature as compared to Rubisco found in C_3 plants.

150. **Assertion:** Besides chlorophyll *a*, blue-green and red algae show the presence of phycobiliproteins.

Reason: Chlorophyll andphycobiliproteins are integrated into thylakoids.

151. **Assertion:** In oxidative phosphorylation, the electrons flow from NADH to O_2.

Reason: In photosynthesis, the electrons flow from H_2O to NADP.

152. **Assertion:** Carotenoids play a protective role for the chloroplasts during photolysis of water.

Reason: Carotenoids pick the nascent oxygen by means of their double bonds and convert the same into molecular state.

153. The following enzymes participate in the initial CO_2 fixation through Calvin cycle:
1. RUBISCO
2. Triose phosphate dehydrogenase
3. Phosphoglyceric kinase

The correct sequence in which these enzymes participate in CO_2 fixation is:
(1) 1, 3, 2 (2) 2, 3, 1
(3) 1, 2, 3 (4) 3, 2, 1

154. Consider the following:
1. Cytochrome b_6 2. Cytochrome f
3. Plastocyanin 4. Plastoquinone

What is the correct sequence of these in the photo-induced electron carriers between PS-II to PS-I in photosynthesis?
(1) 4, 1, 2, 3 (2) 3, 4, 1, 2
(3) 1, 2, 3, 4 (4) 2, 3, 4, 1

*155. The substrate for photorespiration is
(1) C_6 – acid (2) C_4 – acid
(3) C_3 – acid (4) C_2 – acid

156. In what respects are the photosynthetic adaptations of C_4 plants and CAM plants similar?
(1) In both cases, the stomata normally close during the day
(2) Both types of plants make their sugar without the Calvin-Benson cycle
(3) In both cases, an enzyme other than rubisco carries out the first step in carbon fixation
(4) Neither C_4 plants nor CAM plants have grana in their chloroplasts

157. Consider the following statements
A. The layer of bundle sheath cells in the leaves of C_4 plants lacks intercellular spaces.
B. The bundle sheath cells in the leaves of C_4 plants lack mitochondria and peroxisomes.

*149. It is due to low temperature sensitivity of pyruvate phosphate dikinase of C_4 plants.
*155. Glycolic acid is a two carbon compound

C. The bundle sheath cells of C_4 plants have large number of chloroplasts and thick walls.

Which of the statements given above is/are correct?

(1) A and B only (2) B and C only
(3) A and C only (4) None

158. Find out the wrong statement
(1) CAM plants open their stomata at night and close during day time.
(2) Splitting of water takes place in the chloroplast membrane
(3) PSI is found in stromal as well as granal thylakoids
(4) Current availability of CO_2 levels is limiting to the C_3 plants

159. A plant biochemist received a specimen from a fellow scientist who noticed that the plant's stomata are closed during the day. The biochemist observed that radioactive carbon supplied in the form of carbon dioxide fed to the plant at night, was first found in organic acids that accumulated in the vacuole. During the day, the label moved to sugars being manufactured in the chloroplast. What was the conclusion of the biochemist?
(1) It is a CAM plant
(2) It is a C4 plant
(3) It is a C3 plant
(4) It is a plant showing pentose phosphate pathway

160. The C_2glycolate cycle is also known as
(1) PCR (2) PCO
(3) PPP (4) EMP

161. Carotenoids are
(1) Glycoproteins
(2) Hydrocarbons
(3) Polysaccharides
(4) Lipoproteins

162. Consider the following statements
1. PEP carboxylase has a high specificity for carbon dioxide and it never picks up oxygen.
2. Kranz anatomy and C_4 metabolism are found in only monocots of hot climates and not in dicots.

Which of the statements given above is/are correct?

(1) 1 only (2) 2 only
(3) Both 1 and 2 (4) Neither 1 and 2

163. Consider the following statements
A. The chloroplast pigments are fat soluble.
B. All the pigments of chloroplast are located in the thylakoid membranes.

Which of the statements given above is/are correct?

(1) A only (2) B only
(3) Both A and B (4) Neither A nor B

164. Which of the following statements is true for photosynthesis?
(1) Dark reactions occur only in dark
(2) Dark and light reactions always occur simultaneously
(3) Dark reactions occur only when light reactions stop
(4) Dark reactions may also occur in dark

165. Which of the following is true ?
(1) The number of O_2 molecules produced (in photosynthesis) per quantum of light absorbed, is called quantum requirement
(2) The number of light quanta needed for the production of one molecule of oxygen during photosynthesis, is called quantum yield.
(3) The quantum requirement of photosynthesis is 8 quanta
(4) Emerson's first effect is also called photosynthetic enhancement.

166. Which of the following is a false statement?
(1) PEP acts as first acceptor of CO_2 in both CAM plants and C_4 plants.
(2) The plants undergoing crassulacean acid metabolism do not undergo C_3 cycle.
(3) In CAM plants there is separation of initial carboxylation and Calvin cycle in time instead of space in C_4 plants.
(4) All of the above

*167. Select the correct statement for photosynthesis
(1) One photosynthetic unit has about 2500 pigment molecules
(2) Carotenoids cannot develop without light.

*167. One PSU has 250-400 pigment molecules.

(3) Due to their special anatomy C_4 plants have very high rate of photorespiration
(4) According to Munch hypothesis source tissue must have high turgor pressure and increased osmotic concentration

168. Select the wrong statement
(1) One Calvin cycle needed to form one glucose molecule
(2) Reduction of one molecule of CO_2 to carbohydrate requires a minimum of 4 quanta of light.
(3) Reduction of $NADP^+$ to NADPH takes place during Calvin's cycle
(4) All are wrong

169. Cyclic photophosphorylation results in the formation of
(1) ATP, NADPH and O_2
(2) ATP
(3) NADPH
(4) ATP and NADPH

170. Palisade parenchyma is absent in leaves of:
(1) Soyabean (2) Gram
(3) Sorghum (4) Mustard

171. Chemiosmosis was first described by
(1) Paul D. Boyer (2) Peter Mitchell
(3) John E Walker
(4) Friedrich Miescher
(Chandigarh CET 2010)

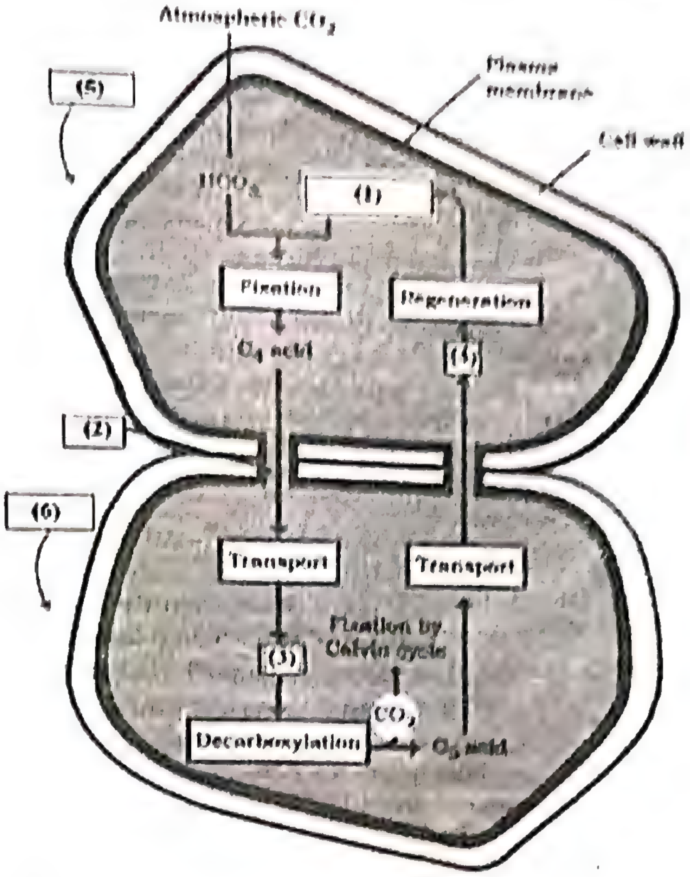
172. Who earned the Nobel Prize in 1961 for mapping of the pathway of carbon assimilation in photosynthesis?
(1) Melvin Calvin (2) Alfonso Corti
(3) Henry Dixon (4) Carl Mobius
(HP PMT 2010)

173. In Photosystem-I (PSI) of light reaction which substrate works as an electron acceptor?
(1) NAD^+ (2) ADP
(3) $NADP^+$ (4) $FADH^+$
(HP PMT 2010)

174. Read the following four statements, A, B, C and D and select the right option having both correct statements.
(A) Z scheme of light reaction takes place in presence of PSI only.
(B) Only PSI is functional in cyclic Photophosphorylation.
(C) Cyclic Photophosphorylation results into synthesis of ATP and $NADPH_2$
(D) Stroma lamellae lack PS II as well as NADP.

Options
(1) B and D (2) A and B
(3) B and C (4) C and D
(CBSE Main 2010)

175. Go through the following figure and find out the option which reflects the correct labelling



(1) (1) RuBP; (2) Plasmodesmata; (3) C_4 acid; (4) C_3 acid; (5) Bundle sheath cell; (6) Mesophyll cell
(2) (1) Phosphoenol pyruvate; (2) Plasmodesmata; (3) C_3 acid; (4) C_4 acid; (5) Mesophyll cell; (6) Bundle sheath cell
(3) (1) Phosphoenol pyruvate; (2) Plasmodesmata; (3) C_4 acid; (4) C_3 acid; (5) Mesophyll cell; (6) Bundle sheath cell
(4) (1) RuBP; (2) Plasmodesmata; (3) C_4 acid; (4) C_3 acid; (5) Mesophyll cell; (6) Bundle sheath cell
(CBSE Main 2010)

176. Kranz anatomy is one of the characteristics of the leaves of
(1) Potato (2) Wheat
(3) Sugarcane (4) Mustard
(CBSE Main 2010)

177. C_4 plants are more efficient in photosynthesis than C_3 plants due to
(1) Lowest rate of photorespiration
(2) Higher leaf area
(3) Presence of larger number of chloroplasts in the leaf cells
(4) Presence of thin cuticle
(CBSE Prelims 2010)

178. The process of ATP synthesis from ADP in the presence of light in chloroplasts is called
(1) Photoelectron transport
(2) Photophosphorylation
(3) Photo system-II
(4) Photorespiration
(HP PMT 2011)

179. CAM helps the plants in
(1) Conserving water
(2) Secondary growth
(3) Disease resistance
(4) Reproduction
(CBSE Prelims 2011)

180. Read the following four statements (A – D)
(A) Both, photophosphorylation and oxidative phosphorylation involve uphill transport of protons across the membrane
(B) In dicot stems, a new cambium originates from cells of pericycle at the time of secondary growth
(C) Stamens in flowers of *Gloriosa* and *Petunia* are polyandrous
(D) Symbiotic nitrogen-fixers occur in free-living state also in soil

How many of the above statements are right?
(1) Four (2) One
(3) Two (4) Three
(CBSE Main 2012)

181. A process that makes important difference between C_3 and C_4 plants is
(1) Glycolysis
(2) Photosynthesis
(3) Photorespiration
(4) Transpiration
(CBSE Prelims 2012)

182. The correct sequence of cell organelles during photorespiration is
(1) Chloroplast–Rough Endoplasmic reticulum–Dictyosomes
(2) Chloroplast–mitochondria–peroxisome
(3) Chloroplast – vacuole – peroxisome
(4) Chloroplast–Golgibodies – mitochondria
(CBSE Prelims 2012)

183. In Calvin cycle, to form one molecule of glucose how many number of ATP and NADPH molecules are utilized?
(1) 12 ATP and 9 NADPH
(2) 6 ATP and 4 NADPH
(3) 18 ATP and 12 NADPH
(4) 20 ATP and 24 NADPH
(HP PMT 2012)

184. In photorespiration the substrate is
(1) Phosphoenol pyruvic acid
(2) Ribulose bi phosphate
(3) ATP
(4) RuBis CO
(HP PMT 2012)

185. The oxygen evolved during photosynthesis comes from water molecules. Which one of the following pairs of elements is involved in this reaction?
(1) Manganese and Chlorine
(2) Manganese and Potassium
(3) Magnesium and Molybdenum
(4) Magnesium and Chlorine
(AIPMT Retest 2015)

186. In photosynthesis, the light independent reactions take place at
(1) Thylakoid lumen
(2) Photosystem I
(3) Photosystem II
(4) Stromal matrix (AIPMT Retest 2015)

187. A plant in your garden avoids photorespiratory losses, has improved water use efficiency, shows high rates of photosynthesis at high temperatures and has improved efficiency of nitrogen utilisation. In which of the following physiological groups would you assign this plant ?
(1) C_4
(2) CAM
(3) Nitrogen fixer
(4) C_3
(AIPMT/NEET 2016)

188. Emerson's enhancement effect and Red drop have been instrumental in the discovery of
(1) Two photosystems operating simultaneously
(2) Photophosphorylation and cyclic electron transport

(3) Oxidative phosphorylation

(4) Photophosphorylation & non-cyclic electron transport

(AIPMT/NEE 2016)

189. In a chloroplast the highest number of protons are found in

(1) Lumen of thylakoids

(2) Inter membrane space

(3) Antennae complex

(4) Stroma (AIPMT/NEE 2016)

190. The process which makes major difference between C_3 and C_4 plants is

(1) Glycolysis (2) Calvin cycle

(3) Photorespiration

(4) Respiration (NEET-2-2016)

191. Phosphoenol pyruvate (PEP) is the primary CO_2 acceptor in

(1) C_3 plants (2) C_4 plants

(3) C_2 plants (4) C_3 and C_4 plants

(NEET 2017)

192. With reference to factors affecting the rate of photosynthesis, which of the following statements is not correct?

(1) Light saturation for CO_2 fixation occurs at 10% of full sunlight.

(2) Increasing atmospheric CO_2 concentration up to 0.05% can enhance CO_2 fixation rate.

(3) C_3 plants respond to higher temperatures with enhanced photosynthesis while C_4 plants have much lower temperature optimum.

(4) Tomato is a greenhouse crop which can be grown in CO_2 – enriched atmosphere for higher yield. (NEET 2017)

ANSWERS

1. (1)	2. (3)	3. (1)	4. (2)	5. (3)	6. (3)	7. (3)	8. (2)	9. (4)	10. (4)
11. (2)	12. (3)	13. (2)	14. (4)	15. (2)	16. (1)	17. (3)	18. (3)	19. (4)	20. (3)
21. (2)	22. (2)	23. (2)	24. (3)	25. (3)	26. (2)	27. (1)	28. (1)	29. (4)	30. (2)
31. (3)	32. (2)	33. (3)	34. (4)	35. (2)	36. (2)	37. (1)	38. (2)	39. (1)	40. (2)
41. (2)	42. (1)	43. (1)	44. (3)	45. (3)	46. (2)	47. (3)	48. (4)	49. (3)	50. (3)
51. (1)	52. (4)	53. (1)	54. (1)	55. (4)	56. (2)	57. (2)	58. (3)	59. (1)	60. (3)
61. (4)	62. (4)	63. (1)	64. (2)	65. (3)	66. (2)	67. (2)	68. (1)	69. (2)	70. (1)
71. (1)	72. (2)	73. (4)	74. (4)	75. (3)	76. (4)	77. (2)	78. (1)	79. (1)	80. (1)
81. (4)	82. (3)	83. (2)	84. (2)	85. (3)	86. (4)	87. (1)	88. (4)	89. (1)	90. (2)
91. (4)	92. (3)	93. (2)	94. (4)	95. (1)	96. (2)	97. (1)	98. (3)	99. (2)	100. (2)
101. (1)	102. (1)	103. (4)	104. (2)	105. (4)	106. (3)	107. (4)	108. (2)	109. (3)	110. (4)
111. (2)	112. (2)	113. (2)	114. (2)	115. (4)	116. (2)	117. (3)	118. (4)	119. (3)	120. (2)
121. (4)	122. (1)	123. (2)	124. (3)	125. (4)	126. (2)	127. (1)	128. (1)	129. (4)	130. (1)
131. (1)	132. (3)	133. (4)	134. (4)	135. (2)	136. (3)	137. (1)	138. (1)	139. (4)	140. (3)
141. (4)	142. (4)	143. (1)	144. (4)	145. (2)	146. (2)	147. (4)	148. (4)	149. (3)	150. (3)
151. (2)	152. (1)	153. (1)	154. (1)	155. (4)	156. (3)	157. (3)	158. (2)	159. (1)	160. (2)
161. (2)	162. (1)	163. (3)	164. (4)	165. (3)	166. (2)	167. (4)	168. (4)	169. (2)	170. (3)
171. (2)	172. (1)	173. (3)	174. (1)	175. (3)	176. (3)	177. (1)	178. (2)	179. (1)	180. (4)
181. (3)	182. (2)	183. (3)	184. (2)	185. (1)	186. (4)	187. (1)	188. (1)	189. (1)	190. (3)
191. (2)	192. (3)								

Chapter 14

Respiration in Plants

THEORY–a quick rundown

Cellular respiration is an energy releasing enzymatically controlled catabolic process which involves a step-wise oxidative breakdown of organic substances.

Respiration provides energy and biochemical intermediates. Biochemical intermediates are used for the synthesis of organic compounds that take part in growth, repair and metabolism. In most cases (as described ahead), complete oxidation of one glucose molecule gives 38 ATP molecules. **The total energy yield from 38 ATP molecules comes to be 1292kJ (one ATP molecule yields 34 kJ of energy). Energy released by one molecule of glucose on complete oxidation corresponds to 2870kJ (686Kcal). Thus the efficiency comes out to be 45%.** It means that only a part of this energy is used to make ATP and much of the energy generated during respiration is released in the form of heat.

Energy stored in ATP is utilised for carrying out different cellular activities. Because of this, ATP is called **energy currency** of the cell.

As pointed out by Lavosier, both combustion and respiration are similar in (a) Breakdown of complex organic substances, (b) Utilization of oxygen, (c) Evolution of CO_2 and water, (d) Release of energy.

Do Plants Breathe?

Plants, unlike animals, have no specialised organs for gaseous exchange but they have stomata and lenticels for this purpose. There are several reasons why plants can get along without respiratory organs. First, each plant part takes care of its own gas-exchange needs. There is very little transport of gases from one plant part to another. Second, plants do not present great demands for gas exchange. Roots, stems and leaves respire at rates far lower than animals do. Only during photosynthesis are large volumes of gases exchanged and, each leaf is well adapted to take care of its own needs during these periods. When cells photosynthesise, availability of O_2 is not a problem in these cells since O_2 is released within the cell. Third, the distance that gases must diffuse even in large, bulky plants is not great. Each living cell in a plant is located quite close to the surface of the plant.

'This is true for leaves', you may ask, 'but what about thick, woody stems and roots?' In stems, the 'living' cells are organized in thin layers inside and beneath the bark. They also have openings called lenticels. The cells in the interior are dead and provide only mechanical support. Thus, most cells of a plant have at least a part of their surface in contact with air. This is also facilitated by the loose packing of parenchyma cells in leaves, stems and roots, which provide an interconnected network of air spaces.

Respiratory Substrates

They are organic substances which can be catabolised to liberate energy. The most common respiratory substrate is **glucose**. In plants the glucose is derived from sucrose, which is the end product of photosynthetic carbon atoms, or from storage carbohydrates. Sucrose is converted into glucose and fructose by the enzyme **invertase**, and these two monosaccharides can readily enter the glycolytic pathway. Fat is the next preferred respiratory substrate. Fats are first broken down into fatty acids and glycerol. The glycerol is first changed to glycerol-3-phosphate which then enters the glycolytic pathway. The fatty acid molecules are degraded and oxidised in the mitochondria by progressive release of two carbon segments in the form of acetyl coenzyme-A. This process is known as oxidation of fatty acids. Acetyl coenzyme-A enters Kreb's cycle and provides energy.

Fats are preferred form of storage fuel. Even excess of carbohydrates and proteins are also converted to fats. This is important for two reasons:

1. The ability of body cells to store carbohydrates in the form of glycogen is low, while ability to store fats is relatively quite high.
2. Fats provide about 2.25 times energy provided by carbohydrates. Therefore, for a given weight gain, a person can store far more energy in the form of fat than in the form of carbohydrate, which is exceedingly important when an animal must be highly motile to survive.

Proteins are used only rarely, as during germination of protein rich seeds and spores. Proteins are normally used as respiratory substrates under starvation conditions only when carbohydrates and fats get depleted. Amino acids differ from carbohydrates and lipids in containing a nitrogenous moiety which is not completely oxidised in the body. The amino group is either exchanged with a keto group of an alpha keto acid to synthesize some non-essential amino acid (process is called transamination) or it is removed and converted to an excretory product, urea, by the process of oxidative deamination. The remaining portion of amino acid containing only carbon, hydrogen and oxygen (known as the carbon skeleton) is oxidized like carbohydrates and lipids. These enter the Kreb's cycle.

Respiration involving proteins is called protoplasmic respiration as compared to floating respiration which uses carbohydrates and fats. Protoplasmic respiration cannot be continued for long as it depletes structural and functional proteins and liberates toxic ammonia.

Gaseous Exchange

There is a regular exchange of O_2 and CO_2 in most of the organisms. Some organisms, especially micro-organisms, do not require oxygen for their respiration. Some of them give out CO_2 while a few do not do so. In these organisms there is no gaseous exchange.

Types of Respiration

Respiration is of two main types, **aerobic** and **anaerobic**. In aerobic respiration organic food is completely oxidised with the help of oxygen into carbon dioxide and water.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6\,CO_2 + 6H_2O + 686 \text{ Kcal}$$

In anaerobic respiration organic food is broken down incompletely to liberate energy without oxygen being used as oxidant. The common products of anaerobic respiration are CO_2, ethyl alcohol and lactic acid.

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2\,CO_2 + \underset{\text{ethyl alcohol}}{2C_2H_5OH} + 50\text{kcal}\ (247\ \text{KJ})$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} \underset{\text{lactic acid}}{2\,C_3H_6O_3} + 36\ \text{kcal}$$

Anaerobic respiration is the only mode of respiration in some micro-organisms. In higher organisms it occurs as a temporary measure. Anaerobic respiration cannot continue for long in higher organisms because (i) It yields little energy. (ii) More substrate is decomposed so that little is left for growth and repair. (iii) Some of the products of anaerobic respiration are harmful.

Respiratory Quotient (RQ) Or Respiratory Ratio

It is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed in respiration.

$$RQ = \text{Volume of } CO_2 \text{ evolved / Volume of } O_2 \text{ absorbed}$$

RQ Equal to Unity

Respiratory quotient is unity if carbohydrates are respiratory substrate and the respiration is aerobic.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6\,CO_2 + 6H_2O \qquad RQ = 6CO_2 / 6O_2 = 1$$

RQ Less than Unity

RQ is less than one when respiration is aerobic but the respiratory substrate is either fat or protein. RQ is about 0.7 for most of the common fats. It occurs during germination of fatty seeds.

$$C_{57}H_{104}O_6 + 80O_2 \longrightarrow 57\,CO_2 + 52\,H_2O \quad RQ = 57\,CO_2/80O_2 = 0.71$$

RQ is about 0.9 in case of proteins, peptones, etc.

RQ is less than 1 because fats and proteins contain less oxygen than the carbohydrates. Therefore, they require relatively greater amount of O_2 for oxidation.

R.Q. is also less than unity when part of CO_2 released is used up non-photosynthetically in lengthening chains of organic compounds.

R.Q. Zero

Succulents do not evolve carbon dioxide during night (when their stomata are open) as the same is used in carbon fixation. They also change carbohydrates to organic acids which utilise oxygen but do not evolve carbon dioxide.

$$2C_6H_{12}O_6 + 3O_2 \longrightarrow 3C_4H_6O_5 + 3H_2O \quad \text{R.Q.} = \text{Zero } CO_2/3O_2 = \text{Zero}$$

RQ More than Unity

(a) RQ slightly more than unity is found when organic acids are broken down as respiratory substrates under aerobic conditions. These organic acids have an oxygen content higher than carbohydrates. This condition is seen in some plants where at times organic acids are used as respirable material.

$$C_4H_6O_5 + 3O_2 \longrightarrow 4CO_2 + 3H_2O \qquad R.Q = 4CO_2/3O_2 \text{ or } 1.3$$
malic acid

$$2C_4H_6O_4 + 7O_2 \longrightarrow 8CO_2 + 6H_2O \qquad R.Q = 8CO_2/7O_2 \text{ or } 1.14$$
succinic acid

$$2\,(COOH)_2 + O_2 \longrightarrow 4CO_2 + 2H_2O + \text{Energy} \qquad RQ = \frac{4CO_2}{1\,O_2} = 4$$
(Oxalic acid)

(b) In anaerobic respiration there is no consumption of oxygen. Carbon dioxide is produced in most of the cases. Therefore, respiratory quotient is infinity.

$$C_6H_{12}O_6 \longrightarrow 2CO_2 + 2C_2H_5OH \qquad RQ = 2CO_2/0 \text{ or infinity}$$

An intermediate value is obtained where an organ is undergoing both aerobic and anaerobic modes of respiration.

Importance. (i) Knowledge of respiratory quotient helps in determining respiratory substrate. (ii) It helps in knowing the type of respiration being performed. (iii) It provides some information about major transformation of food materials.

Factors Affecting Respiration (Some Important Facts)

Light. High light intensity increases intensity of respiration in both photosynthetic and non-photosynthetic organs of plants. It may be due to increased synthesis of organic food, wider opening of stomata and rising of temperature.

Oxygen. The minimum oxygen concentration up to which aerobic respiration can take place is known as **extinction point**. It usually lies between 3-10% of O_2. When O_2 concentration falls, a period is approached where both aerobic and anaerobic respirations go on simultaneously. It is called **transition period.**

At high concentration oxygen acts as a toxic substance. Toxicity results due to reduction of molecular oxygen (O_2) to superoxide free radical (O_2^-). It is highly reactive and may damage DNA, proteins and membranes. Superoxide-mediated damage may be a factor in the aging process. Vitamin C and vitamin E play a role in detoxifying superoxide and other harmful free radicals.

Mineral salts. A number of minerals are required as activators or constituents of respiratory enzymes, *e.g.*, Fe, Cu, K, Mg etc. Nitrogen and phosphorus are required for formation of proteins (and hence enzymes). Boron and molybdenum act as depressants at high concentrations.

The rate of respiration increases during absorption of salts. This increase in rate of respiration is called salt respiration.

Stage of development. Plants show different rates of respiration at different stages of development. There is a burst in respiration rate at the time of seed germination. A slight rise is observed during flower formation. The respiratory rate increases during development of fruits. The rate decreases afterwards but in many cases there is a sharp increase during the ripening of fruits. **It is called climacteric rise. It is accompanied by the evolution of ethylene.**

Aerobic Respiration

The common mechanism of aerobic respiration is also called **common pathway** because its first step, called **glycolysis**, is common to both aerobic and anaerobic modes of respiration. The common aerobic respiration consists of four steps – glycolysis, Krebs cycle, Oxidation of pyruvate, and terminal oxidation. (Some split the process of aerobic respiration into five steps— glycolysis, oxidation of pyruvate, Kreb's cycle, electron transport chain and chemiosmotic ATP synthesis).

Glycolysis

It is also called **EMP pathway**-Embden, Meyerhof and Parnas. It is the process of breakdown of glucose or similar hexose sugar to two molecules of pyruvic acid through a series of enzyme mediated reactions releasing energy (as ATP) and reducing power (as $NADH_2$). It occurs in the cytoplasm.

Phosphofructokinase is the rate limiting enzyme of glycolysis in most tissues and the major regulatory enzyme of glycolysis. It is subject to allosteric inhibition by ATP and citrate.

Although most of the reactions of glycolysis are reversible, three are markedly exergonic and must therefore, be considered physiologically irreversible. These reactions, catalysed by hexokinase, phosphofructokinase, and pyruvate kinase, are the major sites of regulation of glycolysis. Cells that are capable of reversing the glycolytic pathway (gluconeogenesis) have different enzymes that catalyze reactions which effectively reverse these irreversible reactions.

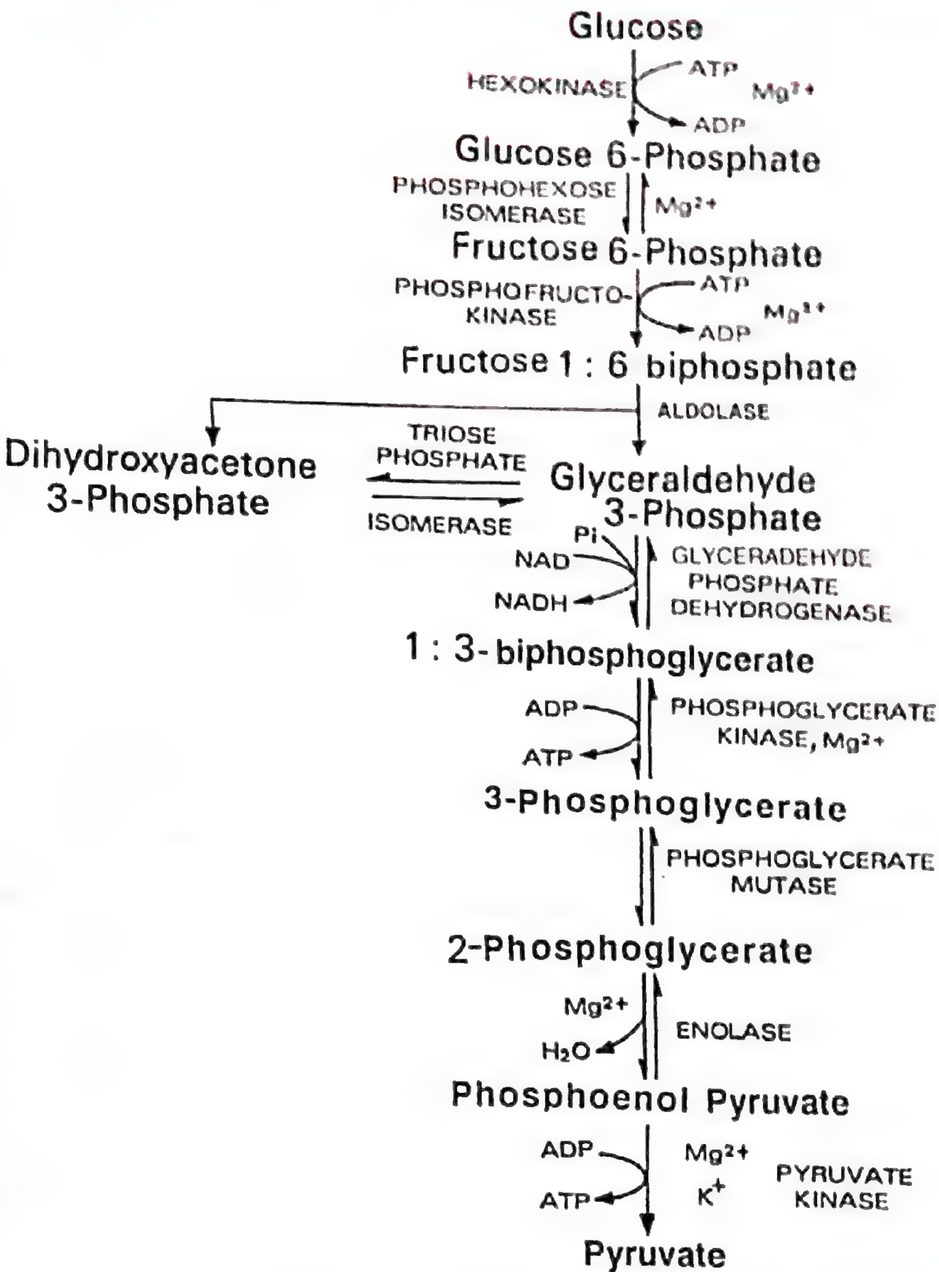


Fig. 14.1. Glycolysis

Net Products of Glycolysis. In glycolysis two molecules of ATP are consumed during double phosphorylation of glucose to form fructose 1: 6 diphosphate. In return four molecules of ATP are produced by substrate level phosphorylation (conversion of 1: 3 diphosphoglycerate to 3-phosphoglycerate and phosphoenol pyruvate to pyruvate). Two molecules of $NADH_2$ are formed at the time of oxidation of glyceraldehyde 3-phosphate to 1:3 diphosphoglycerate. The net reaction is as follows:

$$\text{Glucose} + 2NAD^+ + 2\,ADP + 2H_3PO_4 + \longrightarrow 2\,\text{Pyruvate} + 2\,NADH + 2H^+ + 2ATP$$

Intermediates of glycolysis are used for synthesis of important biochemicals. For example, phosphoenol pyruvate yields shikimic acid which is used in synthesis of amino acids, tryptophan, tyrosine and phenylalanine. Tryptophan is raw material for IAA synthesis. The amino acids are employed for synthesis of proteins, alkaloids, flavonoids and lignin. Similarly, pyruvic acid forms amino acid alanine.

READ AND DIGEST

- Glycolysis involves oxidation without the direct use of oxygen. The oxidation is actually a process of dehydrogenation.
- The part of glycolysis from phosphorylation of glucose to splitting of fructose 1:6 diphosphate is called preparatory phase. The rest of the part constitutes pay-off phase.
- Hexokinase is an allosteric enzyme. It is strongly inhibited by its product, glucose-6-phosphate.
- Mature RBCs contain no mitochondria, so they are totally dependent on glycolysis for ATP production.

Krebs Cycle

The cycle was discovered by Hans Krebs. For this pioneering work, he was awarded Nobel Prize in 1953. It occurs inside mitochondria. It is also known as **citric acid cycle** or **tricarboxylic**

Fig. 14.2. **Krebs Cycle.**

acid (TCA) cycle after the initial product. **Krebs cycle is stepwise oxidative and cyclic degradation of activated acetate derived from pyruvate.**

Oxidation of Pyruvate to Acetyl-CoA. Pyruvate enters mitochondria. It is **decarboxylated oxidatively** to produce CO_2 and NADH. The product combines with sulphur containing coenzyme A to form acetyl CoA or activated acetate. This reaction is called Link reaction or Gateway step and it takes place in the matrix of mitochondria.

$$\text{Pyruvate} + NAD^+ + \text{CoA} \xrightarrow[\text{dehydrogenase}]{\text{Pyruvate}} \text{Acetyl CoA} + NADH + H^+ + CO_2$$

Acetyl CoA functions as **substrate entrant** for Krebs cycle. **The acceptor molecule of Krebs cycle is a 4-carbon compound oxaloacetate.** Acetyl CoA combines with oxalo-acetate to form a tricarboxylic 6-carbon compound called citric acid. It is the **first product** of Krebs cycle.

Succinate dehydrogenase is the only membrane bound enzyme of Kreb's cycle. In eukaryotes, it is attached to mitochondrial membrane and in prokaryotes to plasma membrane.

A molecule of glucose yields two molecules of $NADH_2$, 2ATP and two pyruvate while undergoing glycolysis. The two molecules of pyruvate are completely degraded in Krebs cycle to form two molecules of ATP, $8NADH_2$, and $2FADH_2$.

$$\text{Glucose} + 4ADP + 4H_3PO_4 + 10\ NAD^+ + 2FAD \rightarrow 6\ CO_2 + {}^4ATP + 10\ NADH + 10\ H^+ + 2\ FADH_2$$

READ AND DIGEST

Pasteur effect. It is the reduction in the amount of breakdown of respiratory substrate and evolution of CO_2 when an anaerobically respiring material is brought in oxygen containing environment. It is due to increased availability of energy and utilization of intermediates of anaerobic respiration.

Terminal Oxidation

It is the oxidation found in aerobic respiration that occurs towards the end of process and involves the passage of both electrons and protons from reduced coenzymes to oxygen.

Terminal oxidation consists of two processes –electron transport and oxidative phosphorylation.

Electron Transport Chain

Inner mitochondrial membrane contains groups of electron and proton transporting enzymes. In each group the enzymes are arranged in a series called **electron transport chain** (ETC) or **mitochondrial respiratory chain** or **electron transport system** (ETS). An electron transport chain is a series of coenzymes and cytochromes that take part in the passage of electrons from a chemical to its ultimate acceptor. The passage of electrons from one enzyme to the next is a downhill journey with loss of energy at each step. At each step the electron carriers include flavins, iron sulphur complexes, quinones and cytochromes. Most of these carriers are prosthetic groups of proteins. Four enzymes are involved in electron transport chain– (i) NADH-Q reductase or NADH- dehydrogenase (ii) Succinate Q-reductase complex (iii) QH_2-cytochrome – *c* **reductase complex** (iv) **Cytochrome *c* oxidase complex.** NADH-Q reductase has two prosthetic groups, flavin mononucleotide (FMN) and iron sulphur (Fe-S) complexes. Both electrons and protons pass from $NADH_2$ to FMN.

$$NADH + H^+ + FMN \longrightarrow FMNH_2 + NAD^+$$

Electron now moves to the FeS complex and from there to a quinone. The common quinone is co-enzyme Q, also called ubiquinone (UQ).

$FADH_2$ produced during Krebs cycle hands over its electrons and protons to co-enzyme Q through FeS complex. The enzyme is succinate-Q reductase complex.

QH_2 cytochrome *c* reductase complex has three components – cytochrome b, FeS complex and cytochrome c_1. Coenzyme Q may also be involved between FeS complex and cytochrome c_1.

Cytochrome c_1 hands over electron to cytochrome *c*.

Cytochrome *c* oxidase complex comprises cytochrome *a* and cytochrome a_3. Cytochrome a_3 **also possesses copper**. It helps in transfer of electron to oxygen.

Oxygen is the ultimate acceptor of electrons. It becomes reactive and combines with protons to form metabolic water.

$$2H^+ + O^{2-} \longrightarrow 2H_2O$$

Energy released during passage of electrons is used by transmembrane complexes to pump protons (H^+) from the matrix side of the inner mitochondrial membrane to the outer chamber. There are three such sites (called energy coupling sites) corresponding to three enzymes present in the electron transport chain (NADH-Q reductase, QH_2-cytochrome *c* reductase and cytochrome *c*-oxidase). This increases proton concentration in the outer chamber of the mitochondria. The difference in the proton concentration on the outer and inner sides of the inner mitochondrial membrane is known as proton gradient.

The standard oxidation-reduction potentials of the electron carriers in the respiratory chain become more positive going from the oxidation of NADH to the reduction of molecular oxygen.

Oxidative Phosphorylation

It is the synthesis of ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (*$NADH_2$ $FADH_2$*) produced in respiration. The enzyme required is called **ATP synthetase**. It is located in F_1 or head piece of elementary particles. ATP-synthetase becomes active in ATP formation only where there is a **proton gradient** having higher concentration of H^+ on the F_0 side as compared to F_1 side (chemiosmotic hypothesis of Peter Mitchel). Increased proton concentration is produced in the outer chamber of mitochondria by the pushing of protons with the help of energy liberated during ETC. Transport of the electrons from $NADH_2$ over ETC helps in pushing three pairs of protons to the outer chamber while two pairs of protons are sent outwardly during electron flow from $FADH_2$.

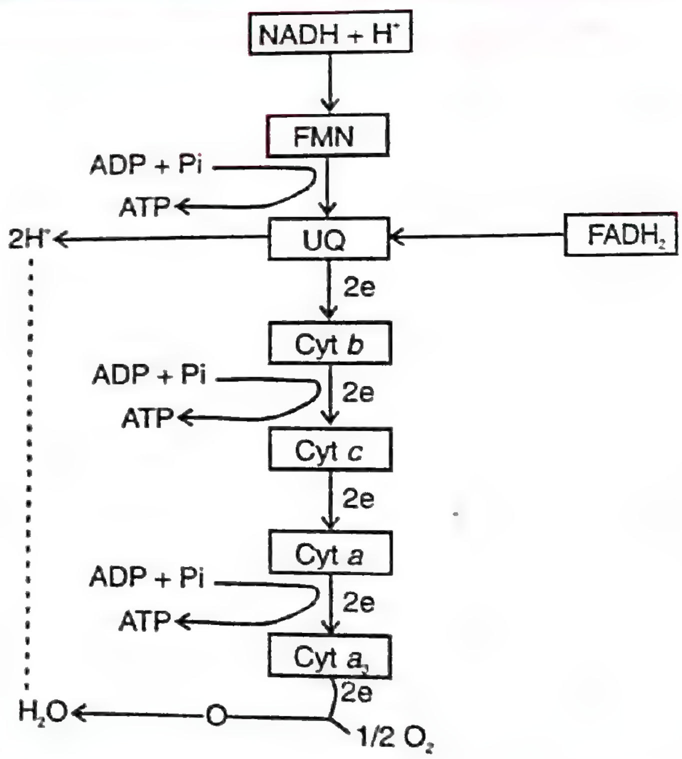


Fig. 14.3. Simplified system of terminal oxidation and oxidative phosphorylation.

Higher concentration of protons in the outer chamber causes the protons to pass inwardly into inner chamber through the inner membrane. The latter possesses special proton channels in the region of F_0 (base) of the $F_0 - F_1$ particles. Flow of protons through the F_0 channel induces F_1 particle to function as ATP-synthetase. The energy of the proton gradient is used in producing ATP.

Glycolysis forms 2 $NADH_2$. Its reducing power is transferred to mitochondria for ATP synthesis. For this, two types of shuttle systems operate at the inner mitochondrial membrane.

Malate shuttle. It functions primarily in heart, kidney and liver. It results in the production of 3 moles of ATP per mole of $NADH_2$. In aerobic prokaryotes, heart, liver and kidney cells, 38 ATP molecules are produced per glucose molecule oxidized. (10 $NADH_2$ = 30 ATP, 2 $FADH_2$ = 4ATP, four formed by substrate level phosphorylation in glycolysis and krebs cycle). Malate shuttle is more common and universal. Passage of ATP molecules from inside of mitochondria to cytoplasm is through facilitated diffusion.

Glycerophosphate shuttle. It functions primarily in brain and skeletal muscles. It results in production of 2 moles of ATP per mole of $NADH_2$ (and not 3 as is seen in malate shuttle). The $NADH_2$ results in formation of $FADH_2$ and thus gives rise to 2 ATP molecules. Two $NADH_2$ molecules produced in cytoplasm during glycolysis give rise to 4 ATP molecules and not 6 ATP molecules. Thus total number of ATP produced during complete oxidation of glucose molecule is two molecules less than the ATP molecules formed through malate shuttle (*i.e.* 38-2 = 36).

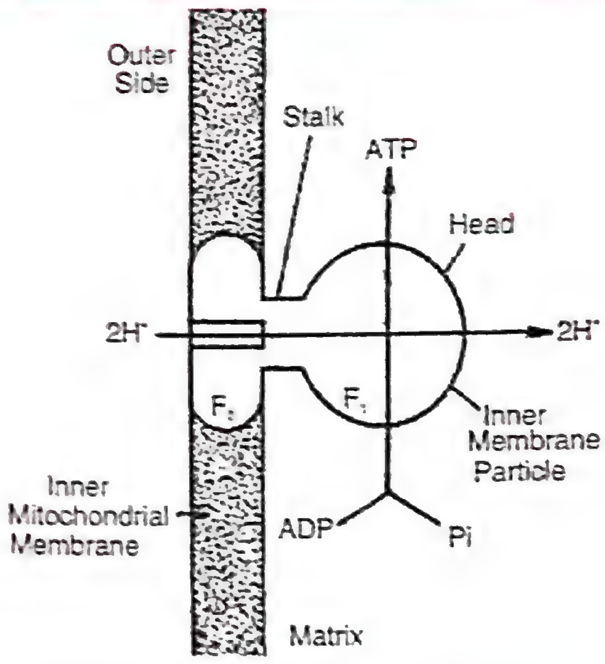


Fig. 14.4. Synthesis by $F_0 - F_1$ particles.

The Respiratory Balance Sheet

It is possible to make calculations of the net gain of ATP for every glucose molecule oxidised; but in reality this can remain only a theoretical exercise. These calculations can be made only on certain assumptions that:

- There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another.
- The NADH synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.
- None of the intermediates in the pathway are utilized to synthesize any other compound.
- Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

But this kind of assumptions are not really valid in a living system; all pathways work simultaneously and do not take place one after another; substrates enter the pathways and are withdrawn from it as and when necessary; ATP is utilized as and when needed; enzymatic rates are controlled by multiple means.

READ AND DIGEST

- Inhibitors of electron transfer from NADH to coenzyme Q include:
  (i) Rotenone, an insecticide ; (ii) Barbiturates (Drugs used for sedation)
- Inhibitors of electron transfer from cytochrome b to cytochrone C_1 include antimycin A, an antibiotic.
- 2 : 4 dinitrophenol allows electron transport but prevents ATP synthesis in ETC. (It is an uncoupler of oxidative phosphorylation
- Thermogenin is a biological uncoupler of oxidative phosphorylation found in the mitochondria of brown adipose tissue. It is used to generate heat by non-shivering thermogenesis which is the primary means of heat generation in hibernating mammals and human infants. Because of uncoupling, oxidation produces much heat and little free energy is trapped in ATP.

- Cyanide prevents transfer of electrons from cytochrome a_3 to oxygen.
- CO inhibits ETC as it completes with O_2 for its binding site on cytochrome oxidase.
- The P : O ratio is a measure of how many moles of ATP are formed from ADP per gram atom of oxygen for a given substrate. For NAD^+ the P : O ratio is approximately 3 : 1. For FAD^+ the P : O ratio is approximately 2 : 1

Significance of Krebs Cycle and its Intermediates.

(i) It is a common pathway of oxidative breakdown of carbohydrates, fatty acids, and amino acids. (ii) Amino acids enter the Krebs cycle directly as glutamate (for α-Ketoglutarate) and asparate (for oxaloacetate) after their deamination. Some amino acids may enter even as pyruvate or acetyl CoA. (iii) Fats break up into fatty acids and glycerol. Glycerol is converted to glyceraldehyde 3-phosphate. Fatty acids undergo β-oxidation to produce acetyl CoA. Acetyl CoA enters Krebs cycle. (iv) Acetyl CoA provides 2-carbon compounds for the synthesis of fatty acids, cutin, aromatic compounds and isoprenoids for forming phytol chain of chlorophyll, carotenoids, steroids, terpenes, gibberellins, etc. (v) α-Ketoglutarate produces amino acid **glutamate**. Oxaloacetate forms aspartate. (vi) Succinyl CoA takes part in synthesis of pyrrole compounds of chlorophyll, cytochrome and phytochrome.

Krebs cycle provides a number of intermediates for anabolic pathways. Therefore, Krebs cycle is **amphibolic** (both catabolic and anabolic).

ATP. Adenosine triphosphate is formed of an adenine, a ribose and a row of three phosphate groups attached to ribose. The last two phosphate groups are attached by bonds of **high energy**. The bond between second and third phosphate groups possesses an energy equivalent of 8.9 Kcals/mole (7 Kcal/mole according to early estimates) while the bond linking the second phosphate groups with the first one has an energy equivalent of 6.5 Kcal/mole. The last phosphate can be very easily broken up and synthesised. The form of energy present in high energy bonds of ATP (and other energy carriers like GTP, UTP or CTP) is **biologically useful energy**. Hence, ATP can function as **energy currency** of the cells.

Synthesis of ATP

ATP is synthesised from ADP and inorganic phosphate (Pi). The reaction (endergonic) is called **phosphorylation**. It is of three types – substrate level phosphorylation, oxidative phosphorylation and photophosphorylation. Substrate level phosphorylation is directly linked to the liberation of energy in chemical reactions of respiration.

$$\text{1 : 3-diphosphoglycerate} + \text{ADP} \rightleftharpoons \text{3-phosphoglycerate} + \text{ATP}$$

Oxidative phosphorylation is linked to terminal oxidation of reduced coenzymes ($NADH_2$, $NADPH_2$ and $FADH_2$) in respiration. The coenzymes release H^+ ions and electrons. The electrons pass over a series of carriers, called electron transport chain.

Photophosphorylation occurs on the thylakoids of chloroplasts.

Utility of Step-wise Oxidation.

(i) The step-wise release of chemical bond energy is easily trapped in forming ATP molecules. (ii) Cellular temperature is not allowed to rise. (iii) Wastage of energy is reduced. (iv) There are several intermediates which can be used in production of many biochemicals. (v) Through their metabolic intermediates, different biomolecules can enter the break down process of respiration.

Anaerobic Respiration

This term is often used in connection with higher organisms where it occurs in the roots of some water-logged plants, muscles of animals and as supplementary mode of respiration in massive tissues. It is the exclusive mode of respiration in some parasitic worms and micro-organisms. In micro-organisms the term **fermentation** is more commonly used where anaerobic respiration is known after the name of product like **alcoholic fermentation, lactic acid fermentation**. In some cases carbon dioxide is evolved. It gives a frothy appearance (L. fermentum – to boil). Buchner found that fermentation could be caused without the living yeast cells by grinding them under pressure and mixing the extract with sugary solution. The enzyme present in the extract was named as **zymase.** Because of the latter, fermentation is also called **zymosis**. *Fermentation is the anaerobic breakdown of carbohydrates and other organic compounds into alcohols, organic acids, gases, etc. with the help of micro-organisms or their enzymes.*

The mechanism of anaerobic respiration is similar to common pathway of aerobic respiration upto glycolysis. Glycolysis breaks down glucose to two molecules of pyruvate, 2 ATP and 2 NADH ($+H^+$). Pyruvate is anaerobically broken down to yield various products depending upon the organism and the tissue.

1. **Ethyl Alcohol Fermentation.** It is seen in fungi (*e.g., Rhizopus*, Yeast) and bacteria. Yeast can respire both aerobically and anaerobically. When O_2 is limiting, plants usually show ethyl alcohol fermentation. It causes fermentation. In the presence of pyruvate decarboxylase and TPP (thiamine pyrophosphate), pyruvate is broken down to acetaldehyde.

$$\text{Pyruvate} \xrightarrow[\textit{decarboxylase, TPP, } Mg^{2+}]{\text{Pyruvate}} \text{Acetaldehyde} + CO_2\ (\uparrow)$$

The acetaldehyde produced is reduced to ethyl alcohol by alcohol dehydrogenase. Hydrogen is obtained from $NADH_2$ produced during oxidation of glyceraldehyde 3-phosphate to 1:3 diphosphoglyceric acid in glycolysis.

$$\text{Acetaldehyde} + \text{NADH} \xrightarrow[\textit{dehydrogenase}]{\textit{Alcohol}} C_2H_5OH + NAD^+$$

2. **Lactic Acid Fermentation.** It occurs in lactic acid bacteria (*e.g., Lactobacillus*), some fungi and muscles. Lactic acid produced in muscles is sent to liver to regenerate glucose. The pyruvic acid is directly reduced by $NADH_2$ to form lactic acid. No CO_2 is produced. The enzyme is lactic dehydrogenase which requires FMN (Flavin Mono-nucleotide) and Zn^{2+}.

$$\text{Pyruvic Acid} + NADH_2 \xrightarrow[\textit{FMN, } Zn^{2+}]{\textit{Lactic Dehydrogenase}} \text{Lactic Acid} + NAD^+$$

In both lactic acid and alcohol fermentation not much energy is released; less than seven per cent of the energy in glucose is released and not all of it is trapped as high-energy bonds of ATP.

Yeasts poison themselves to death when the concentration of alcohol reaches about 13 per cent.

Anaerobic respiration produces very little energy as compared to aerobic respiration. The reasons are (a) There is incomplete breakdown of respiratory substrate. (b) $NADH_2$ produced during glycolysis is re-utilised (d) Electron transport chain is absent.

• NADH is oxidized to NAD^+ rather slowly in fermentation, however the reaction is very vigorous in case of aerobic respiration.

Importance. (i) It is important during periods of oxygen deficiency. (ii) Alcoholic fermentation is used for the production of various types of beers, whisky and wines. (iii) Carbon dioxide of alcoholic fermentation is used for making the bread light. (iv) Vinegar is obtained by the fermentation activity of acetic acid bacteria. (v) In dairy industry action of lactic acid bacteria is used to convert milk sugar to lactic acid. Lactic acid coagulates the milk protein casein and the droplets of milk fat fuse. (vi) Tea and tobacco leaves are cured (or removed of their bitterness). (vii) Production of industrial alcohols and organic acids. (viii) Retting or separation of stem fibres is carried out with the help of bacterial fermentation of softer tissues. (ix) Cleaning of raw hides is a fermentative bacterial activity. (x) Ensilage or preserved fodder is prepared by keeping green chopped fodder in silo where bacterial action causes softening and release of preserving acids. (xi) Decomposition of dead bodies of organisms is carried out by fermentation. However, the fermenting organisms also spoil out food and may cause food poisoning.

Fat Respiration

Fat is a triglyceride being made of a molecule of glycerol and three molecules of fatty acids. Glycerol requires one ATP molecule for forming glyceraldehyde phosphate. The latter enters glycolysis. It yields 18-19 ATP molecules, one half of glucose. Fatty acids undergo b-oxidation. It forms acetyl CoA, $NADH_2$ and $FADH_2$. Acetyl CoA enters Krebs cycle.

Red and White Muscle Fibres

Red muscle fibres contain abundant myoglobin, the pigment which stores oxygen. White muscle fibres have little of myoglobin. Red muscle fibres can, therefore, continue work over long periods by using myoglobin stored oxygen and hence performing aerobic respiration. White muscle fibres can do work continuously only for short duration because of exhaustion of oxygen and switch over to anaerobic respiration. Anaerobic respiration forms lactic acid that causes fatigue. Athletes having higher proportion of red or dark muscle fibres are better to participate in long duration events like long distance running, swimming, etc. Similarly, athletes having higher proportion of white or pale muscle fibres are physiologically suited for short duration events like sprint, shot put, high jump, etc.

Pentose Phosphate Pathway

It is also called oxidative phosphate pathway, hexose monophosphate shunt (HMP), Warburg-Limpam-Dickens Cycle and phosphogluconate shunt. It is an alternate mechanism of glucose oxidation. It occurs inside the cytoplasm. PPP is favoured by the presence of NADP in the cytoplasm. It is more common in mature cells. For every six molecules of glucose only one is completely oxidized while the other five are regenerated. Oxidation of glucose is linked to the formation of $NADPH_2$ i.e., oxidation is achieved by dehydrogenation as in glycolysis. CO_2 is liberated.

Complete degradation of one molecule of glucose produces 12 $NADPH_2$. It is equivalent to 36 ATP molecules. It compares favourably with the common pathway of aerobic respiration which liberates 38 ATP molecules per glucose molecule.

Glycolysis and Pentose phosphate shunt are two major pathways for the catabolism of glucose but the two pathways have little in common. Although glucose-6-phosphate is common to both pathways, both are markedly different from each other. Oxidation utilizes NADP in pentose phosphate pathway rather than NAD. CO_2 which is not produced in glycolysis, is a characteristic product in pentose phosphate pathway. Also no ATP is generated in the pentose phosphate pathway, whereas ATP is a major product of glycolysis.

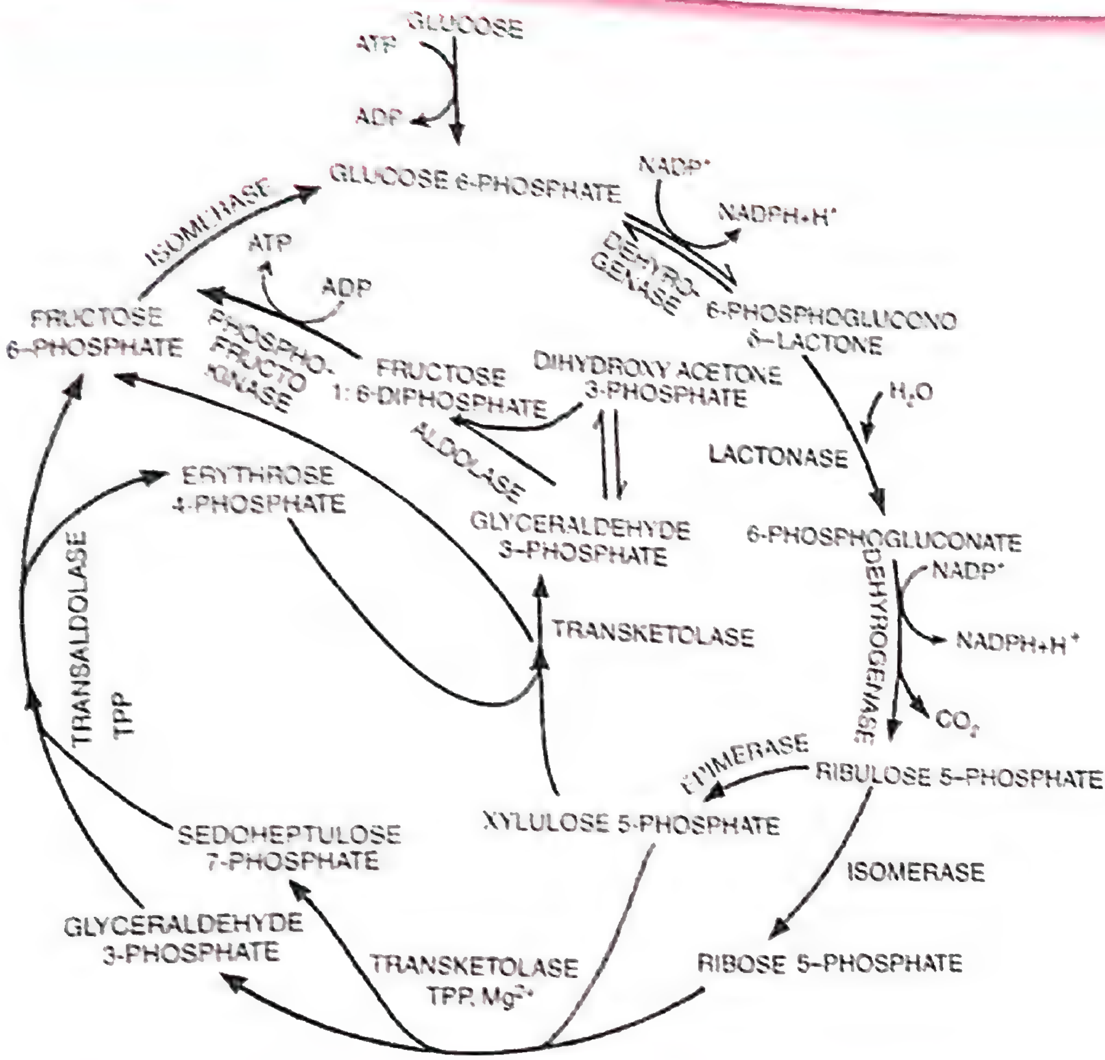


Fig. 14.5. Schematic representation of Pentose phosphate Pathway (Hexose Monophosphate Shunt).

Importance. (i) It produces $NADPH_2$ for various biosynthetic reactions. (ii) It produces a number of tetroses and pentoses for the synthesis of nucleosides, nucleotides, nucleic acids, lignin, anthocyanins, indole 3-acetic acid and many other compounds.

- RBCs depend on HMP shunt for NADPH, which is required to maintain glutathione in the reduced state. Reduced glutathione is needed to maintain the integrity of the RBC membrane.
- The deficiency of enzyme G-6-PD can cause red blood cell disorder hemolytic anaemia. In the absence of this enzyme, RBCs are not able to maintain reduced glutathione levels. Like sickle-cell anaemia, this trait is thought to have been selected by resistance to the malaria parasite.

READ AND DIGEST

- HMP shunt is most active in the RBCs, liver, mammary glands, adipose tissue and the adrenal cortex.
- **Glyoxylate or Glyoxylic acid cycle:** It is a variant of Krebs cycle. It is also known as dicarboxylic acid cycle. It occurs in microbodies known as glyoxysomes. In contrast to Kreb's cycle, it is a synthetic system. In this cycle two molecules of acetyl CoA are used up to produce a molecule of a 4-carbon compound (malic acid or oxaloacetic acid). This cycle is involved in the formation of organic acids during the ripening of fruits. It also provides pathway for conversion of fats into carbohydrates. The β-oxidation of fatty acids produces acetyl CoA, which is fed to the glyoxylic acid cycle for producing 4-carbon compounds and then carbohydrates.

- **Bioluminescence:** It is the phenomenon of emission of light by organisms.
- In respiration dry weight of body is decreased
- Respiration (dark respiration) occurs in every living cell throughout day and night. In prokaryotes it occurs in cytoplasm and cell membrane but in eukaryotes in cytoplasm and mitochondria.
- Respiration decreases with increasing age but increases on injury or infection.
- Respiration is a slow energy releasing process but does not raise the temperature of body or cell. Most of the energy released is trapped in ATP and rest is liberated as heat to control body temperature.
- Respiration is similar to combustion (burning) in using O_2, evolving CO_2, and releasing energy. But respiration is found in living cells and is an enzymatic controlled process in which energy in released slowly and step wise.
- 1 molecule of glucose yields 56Kcal or 2 ATP in anaerobic respiration and 686000 calories (686k cal) or total of 38 ATPin aerobic respiration (but net gain of ATP in eukaryotes is 38 or 36 depending upon type of shuttle system. In prokaryotes it remains 38 ATP aerobic respiraion.Thus ratio of ATP in aerobic and anaerobic respiration is 36 : 2 *i.e.*, 18 : 1 or 38 : 2 *i.e.*, 19 : 1.
- Of these 36 ATP molecules, 4 are formed directly by substrate phosphorylation and 32 by oxidative phosphorylation through ETS.
- Ratio of CO_2 production in between aerobic and anaerobic respiration is 3 : 1 because 6 CO_2 are produced in aerobic breakdown of one molecule of glucose and 2 CO_2 are produced when one molecule of glucose is oxidised anaerobically.
- One molecule of sucrose yields 76 ATP as sucrose is a disaccharide.
- One molecule of glucose (180g) yields 264 g CO_2 on complete oxidation.
- Respiration is exergonic (exothermic) but ATP **synthesis is endothermic** (endergonic) process.
- **CO_2 compensation point.** The concentration of CO_2 at which photosynthesis release O_2 to just compensate respiration. Here there is no gain or loss of dry weight.
- If CO_2 contents of atmosphere is as high as 300ppm, plants would grow for sometime and then die. In high concentration of CO_2, respiration rate decreases.
- **Climacteric respiration** is sudden increase in respiration during the ripening of some fleshy fruits like banana.
- **Extinction Point**. It is the minimum concentration of oxygen below which aerobic respiration stops. It is 2 to 4% of O_2 *i.e.*, below it respiration stops.
- α-ketoglutaric acid acts as a **connecting link** between respiration and protein synthesis. It is a key substance in nitrogen metabolism.
- Dormant seeds represent a state of autooxidation.
- Green leaves starve in dark and use protein in respiration. Etiolated leaves show a fall in respiration rate.
- Very high concentration of sugar decreases respiration due to osmotic effect.
- If a cell is transferred from high temperature to low temperature suddenly, there will be an increase in the rate of respiration for first few hours.
- There is an increase in rate of respiration when a tissue or plant is transferred from water to salt solution. It is called **salt respiration**.
- Acetyl~CoA acts as connecting link between glycolysis and Krebs' Cycle and oxidation of fats.
- PGAL acts as connecting link between respiration and photosynthesis.
- P/Q ratio : No of molecule of ATP generated per atom of oxygen utilised in respiration. For NAD it is 3 and 2 for FAD linked substrates. (P = photosynthesis; O = oxygen).
- NAD (Nicotinamide Adenine dinucleotide) is called coenzyme I. It is an universal accepter of Hydrogen atom. Previously it was called DPN (diphospho phyridine nucleotide). NADP (coenzyme II) is also a hydrogen acceptor in eukaryotes. Previously it was known as TPN (Triphospho pyridine nucleotide) $NADH_2$ or $NADPH_2$ is called Reducing Power as it containg about 52.6 k cal. Usually NAD carries electrons to ETS and NADP carries electrons to synthetic reactions and supply H to reduce CO_2 in photosynthesis.
- **Viruses do not show respiration.**
- **Kuhne's tube** is used to demonstrate fermentation. Rate of respiration in plant is measured by **Ganong's respirometer** and **warburg manometer**.
- Cyanide resistant respiratory pathway is found in plants in **climacteric** fruits under cold stress. ATP synthesis does not occur. The reduced coenzymes oxidise to produce heat energy.
- 1g Alcohol gives 7.1 Kcal energy while 1 mole of glucose (*i.e.*, 180 g) gives 686 Kcal.

MULTIPLE CHOICE QUESTIONS

1. Respiration is
(1) anabolic and exothermic
(2) anabolic and endothermic
(3) catabolic and endothermic
(4) catabolic exothermic

2. In respiration, 180 g sugar and 192 g oxygen produce
(1) 132g CO_2 + 54 g H_2O + 337 k cal
(2) 264 g CO_2 + 108 g H_2O + 686 k cal
(3) 528 g CO_2 + 216 g water + 686 kcal
(4) Large amount of CO_2 and energy

3. When respiratory substrate is fat, respiration is called
(1) protoplasmic respiration
(2) floating respiration
(3) cellular respiration
(4) dark respiration

4. Efficiency of respiration is
(1) 50% (2) >50% (3) <50% (4) 100%

5. Glyceraldehyde 3–phosphate (PGAld or GAP) is oxidised during glycolysis. What happens to the hydrogen atom and the electron that are removed during its oxidation ?
(1) They reduce NAD^+
(2) They oxidise NAD^+
(3) They are transferred to Pyruvic acid
(4) They are removed by FAD

6. In the formation of Acetyl Co~A from pyruvic acid in mitochondria, pyruvic acid gets
(1) oxidised
(2) decarboxylated
(3) both (1) and (2)
(4) reduced and isomerised

7. When a yeast produces wine, which is not formed ?
(1) Acetaldehyde (2) Ethyl Alcohol
(3) CO_2 (4) Acetyl coenzyme A

8. The net gain of glycolysis of one molecule of glucose is the formation of
(1) 2NADH + H^+ + 4ATP+1 Pyruvic acid
(2) 2NADH + H^+ + 2ATP+2 Pyruvic acid
(3) 8ATP +2NADH + H^+ +2 Pyruvic acid
(4) 8ATP+2NADH+H^++ 2 Pyruvic acid +CO_2

9. The oxygen in H_2O produced during ETC comes from
(1) $C_6H_{12}O_6$ (2) O_2
(3) CO_2 (4) Both (1) and (2)

10. How many oxygen molecules are used in glycolysis of one molecule of glucose ?
(1) 1/2 (2) 1 (3) 0 (4) 2

11. Which intermediate compound acts as connecting link between glycolysis and Krebs' cycle/link between carbohydrate and fat metabolism
(1) OAA (2) Cytochrome
(3) Acetyl Co~A (4) Pyruvic acid

12. When yeast ferments glucose, the products are
(1) $C_2H_5OH + CO_2$ + Energy
(2) C_2H_5OH + Energy
(3) $CO_2 + H_2O$ + Energy
(4) $CH_3OH + H_2O$ + Energy

13. Energy formed during conversion of glucose to pyruvate is equvalent to
(1) 32 ATP (2) 16 ATP
(3) 8 ATP (4) 4 ATP

*14. Which is formed through phosphorylation in glycolysis ?
(1) Fructose 1–6 Biphosphate
(2) DHA–3–phosphate
(3) Both are correct
(4) Glyceraldehyde–3–phosphate

15. Which step of glycolysis requires pyruvic kinase, Mg^{++}, K^+ and ADP ?
(1) Conversion of PEP into pyruvic acid
(2) Conversion of 3PGA into 2PGA
(3) Cleavage of Fructose 1-6 Biphosphate
(4) All of the above

*16. One molecule of glucose requires 2 ATP to get phosphorylated to form Fructose 1–6 Biphosphate in glycolysis. How many ATP are

*14. Glucose on phosphorylation by ATP forms glucose 6—phosphate. It isomerises into fructose 6 phosphate which on further phosphorylation forms fructose 1, 6 biphosphate (previously called fructose 1, 6-Di phosphate). It cleaves to form two tautomers in dynamic equilibrium which are DHAP and PGAL. PGAL (= GAP) is further phosphorylated by H_3PO_4 to form 1, 3 bi phosphoglyceric acid.

*16. Whether, it is glucose or fructoso, reactions are same

used in the same process if the substrate is fructose ?

(1) 1 (2) 2 (3) 0 (4) 4

17. Amphibolic cycle that occurs only in aerobic condition is

(1) EMP pathway (2) Glycolysis
(3) Krebs' cycle (4) ETC

*18. During respiration, pyruvic acid is

(1) broken to form a 2-carbon compound and CO_2
(2) produced in Krebs' cycle
(3) formed only if fat is used
(4) produced only in aerobic condition

19. In Krebs' cycle the first product is citric acid which is a 6-carbon compound. It is formed by a condensing irreversible reaction between

(1) OAA and puruvic acid
(2) OAA and Acetyl Co~A
(3) Pyruvic acid and Acetyl Co~A
(4) OAA and citrate synthetase

20. Aerobic glycolysis is _______ times efficient than anaerobic glycolysis

(1) 2 times (2) 4 times
(3) 10 times (4) 18 times

21. Ratio of CO_2 produced in aerobic and anaerobic respiration is

(1) 3 : 1 (2) 2 : 1 (3) 4 : 1 (4) 1 : 1

22. One molecule of pyruvic acid produces _______ molecules of CO_2 in mitochondrion

(1) 3 (2) 2 (3) 4 (4) 6

23. Upon complete oxidation of 1 molecule of pyruvic acid in mitochondrial respiration the molecules of ATP generated are

(1) 38 (2) 30 (3) 8 (4) 15

24. Most of the energy in cell is liberated by the oxidation of carbohydrates when

(1) pyruvic acid is changed into CO_2 & H_2O
(2) pyruvic acid is converted into Acetyl CoA
(3) sugar is converted into Pyruvic acid
(4) glucose is converted into Alcohol & CO_2

*25. How much energy is conserved as ATP per mole of O_2 reduced into H_2O ?

(1) 36 (2) 38 (3) 6
(4) 36 in eukaryotes and 38 in prokaryotes.

26. Approximately how much Kcal energy is produced in biological oxidation per mole of oxygen reduced ?

(1) 150 (2) 3600
(3) 686 (4) 110

27. Flow of electons in ETS is

(1) Fe+++ → Cu^+ > Fe++
(2) Fe++ → Fe+++
(3) $Fe^{+3} \to Fe^{+2} \to Fe^{+3}$
(4) $Fe^{+2} \to Fe^{+3} \to Fe^{+2}$

28. Krebs' cycle was discovered by Krebs in Pigeon muscles in 1940. Which step is called **Gateway Step/Link reaction** in aerobic respiration ?

(1) Glycolysis
(2) Formation of acetyl Co~A
(3) Citric acid formation
(4) ETS Terminal oxidation

29. In Kreb's cycle

(1) Acetyl coenzyme A undergoes 4 oxidations and 2 decarboxylations
(2) Pyruvic acid undergoes 4 oxidations and 2 decarboxylations
(3) TCA undergoes 4 oxidations and 4 decarboxylations
(4) OAA undergoes 4 oxidations and 2 decarboxylations

30. Flow of electrons in ETS is NADH + H^+ (NADPH + H^+)→ FMN→FeS protein→CoQ→ cyt b→cyt c_1→cyt c→ cyt a→cyt a_3→o". At three steps ATP is formed (oxidative phosphorylation). Where does II ATP is formed?

(1) Between $NADH_2$ and FMN
(2) Cyt b and Cyt c_1
(3) Cyt a and Cyt a_3
(4) FMN - FeS protein

31. The enzyme/s that convert pyruvic acid into ethanol is/are

(1) carboxylase
(2) dehydrogenase
(3) decarboxylase and dehydrogenase
(4) oxidase and decarboxylase

32. Oxidation of one molecule of glucose yields 38 mols of ATP in the proportion of

(1) all the 38 mols in mitochondrion
(2) 8 outside mitochondria and 30 inside mitochondrion

*18. 2—C compound is Acetyl Co~A (active acetate).
*25. For ½O_2, 3ATP are formed.

(3) two glycolysis and 36 inside the Krebs' cycle

(4) two outside and 36 inside the mitochondria.

33. Inner mitochondrial membrane possesses enzymes

(1) ATPase, succinic dehydrogenase cytochrome oxidase.

(2) Malate dehydrogenase, citrate synthetase

(3) Diphosphokinase and cyclase

(4) citrate synthetase

34. In electron transport system, the cytochrome which donates electron to free oxygen is

(1) cyt b (2) cyt c_1

(3) cyt a (4) cyt a_3

35. The molecule that regularly enters through the inner membrane of mitochondrion is

(1) ATP (2) pyruvic acid

(3) glucose (4) citric acid

36. Cyt a_3 has

(1) Fe and Cu (2) Fe

(3) Mn (4) Fe, Mn + Cl

37. Which of the following is common to glycolysis and Krebs' cycle ?

(1) Substrate level phosphorylation

(2) Photophosphorylation

(3) $FADH_2$ formation

(4) Both occur in matrix of mitochondria

38. ETS in bacteria is found in

(1) cell membrane (2) cell wall

(3) cytoplasm (4) mitochondrion

39. In cell respiration, which does not involove EMP pathway ?

(1) Pyruvic acid into CO_2 and H_2O

(2) Glucose into lactic acid

(3) Glucose into CO_2 and H_2O

(4) Glucose into alcohol

40. Zymosis is also called

(1) fermentation

(2) action of zymogens

(3) pasteurization

(4) synapsis of chromosomes

41. Correct sequence of events in Krebs' cycle is

(1) Acetyl CoA → citrate → pyruvate α-keto-glutarate → succinate → malate → fumarate → OAA

(2) Acetyl CoA → citric acid → α-keto-glutaric acid → succinic acid → fumaric acid → malic acid → OAA

(3) Acetyl CoA → citric acid → malic acid → α-ketoglutaric acid → succinic acid → OAA

(4) Pyruvic acid → Acetyl CoA → citrate → malate → fumarate

42. RQ is

(1) $\dfrac{\text{vol of } CO_2 \text{ released in respiration}}{\text{vol of } O_2 \text{ consumed in respiration}}$

(2) $\dfrac{\text{vol of } CO_2 \text{ consumedinphotosynthesis}}{\text{vol of } O_2 \text{ consumedinrespiration}}$

(3) $\dfrac{\text{vol of } CO_2 \text{ taken in photosynthesis}}{\text{vol of } CO_2 \text{ released in respiration}}$

(4) $\dfrac{\text{vol of } CO_2 \text{ taken in photosynthesis}}{\text{vol of } CO_2 \text{ released in photosynthesis}}$

43. During starvation, RQ value will be

(1) O (2) less than unity

(3) more than unity (4) unity

44. When respiratory substrate is cereal/ starchsprouting potato tuber, then RQ value is

(1) 0 (2) unity (3) >1 (4) <1

45. In anaerobic condition, value of RQ will be

(1) 1 (2) 2 (3) infinity (4) 0

46. If a substance is rich in oxygen, then value of RQ (Respiratory Quotient) will be

(1) unity (2) less than 1

(3) greater than 1 (4) 0

47. RQ value in succulents/CAM plants in night is

(1) <1 (2) unity (3) >1 (4) 0

48. When production of CO_2 is more than intake of O_2, the respiratory substrate is

(1) sucrose (2) organic acid

(3) glucose (4) fat/protein

49. Enzyme ATPase is found in........of oxysome.

(1) Head (F_1) (2) Base (F_0)

(3) Stalk (4) $F_0 - F_1$

50. Which of the following observations most strongly support the view that mitochondria contain electron transfer enzymes aggregated into compact associations ?

(1) Mitochondria have a highly folded inner membrane

(2) Disruption of mitochondria yield mem-

brane fragments which are able to synthesize ATP
(3) A contractile protein able to utilize ATP is found in mitochondria
(4) None of the above.

*51. The Nobel Prize for the discovery of TCA cycle and ATP biosynthesis was awarded to
(1) Hans Krebs (2) Lipman
(3) Krebs and Lipman jointly
(4) Vishniac and Ochoa

52. In anaerobic respiration, pyruvic acid in muscles forms
(1) ATP (2) Lactic acid
(3) Acetyl Co~ A (4) NAD

53. Terminal oxidation in ETS is
(1) stoppage of oxidation
(2) final release of protons
(3) only step where actual oxidation using O_2 occurs
(4) ETS initiation

54. Krebs' cycle also called TCA (Tricarboxylic acid cycle) or citric acid cycle (organic acid cycle). It is also called metabolic sink as it is
(1) common pathway for carbohydrates. fats and proteins (amino acids)
(2) common pathway for carbohydrates and fats only
(3) common pathway for carbohydrates and organic acids only
(4) none of the above

*55. One turn of Krebs' cycle for the oxidation of 1 mol of sucrose produce how many ATP molecules ?
(1) 12 (2) 24 (3) 22 (4) 11

56. Acetaldehyde is intermediate product in
(1) lactic acid fermentation
(2) ethyl alcohol fermentation
(3) Kreb's cycle
(4) glycolysis

57. One molecule of sucrose yields............ATP in anaerobic respiration
(1) 2 (2) 4 (3) 38 (4) 36

58. One molecule of NADH + H^+/NADPH + H^+ has sufficient energy to generate 3 ATP through ETS. This energy is approximately
(1) 52.6 k cal (2) 24.4 k cal
(3) 18 k cal (4) 36 k cal

59. Proteins enter into Krebs' cycle through
(1) $\propto$-Ketoglutarate (2) OAA
(3) Both (1) & (2) (4) None of these

60. If fructose 1– 6 Bisphosphate is oxidised in aerobic respiration, the ATP production will be
(1) 36 (2) 38 (3) 32 (4) 40

61. Respiration of starved leaves (consuming proteins) is called
(1) protoplasmic respiration
(2) floating respiration
(3) photorespiration
(4) oxidative phosphorylation

62. To start respiration, a living cell requires
(1) only glucose (2) glucose + O_2
(3) glucose, ATP and enzymes
(4) glucose + enzymes

63. The rate of oxidative phosphorylation and ATP synthesis is related with
(1) quantasomes (2) ribosomes
(3) elementary particles (4) lysosomes

64. Enzymes involved in oxidative decarboxylation of pyruvic acid are found in
(1) cytoplasm
(2) matrix of Mitochondrion
(3) $F_0 - F_1$ particles (4) oxysomes

65. As compared to anaerobic respiration the energy gained during aerobic respiration is
(1) 8 times (2) 19 times
(3) 12 times (4) 36 times

66. Cytochromes are found in
(1) entire inner mitochondrial membrane
(2) cristae only
(3) matrix of mitochondria
(4) oxysomes

67. Cytochrome oxidase is related with
(1) Cyt b (2) Cyt a_3 (3) Cyt c_1 (4) Cyt. c

68. Cytochromes are component of ETC and act as

*51. TCA cycle was discovered By Hans Krebs (1940). ATP formation system (ATP cycle) is called Lipman system after the name of its discoverer. But ATP was discovered by Lohmann.

*55. Whether it is glucose/sucrose, one turn of Krebs' cycle produces 12 ATP. In sucrose there will be in all four turns of Krebs' cycle instead of two as in case of glucose and, therefore, total ATP production will be two times more than glucose that is 76 ATP.

(1) O_2 acceptor (2) H_2 acceptor
(3) Electron acceptor (4) All of these

69. The rate of respiration increases
(1) where no light is present
(2) in winter
(3) in high temperature
(4) in rainy season

70. All enzymes of TCA cycle except succinic dehydrogenase and cytochrome oxidase are found in
(1) cytosole and oxysomes
(2) matrix of mitochondrion
(3) inner membrane of mitochondrion
(4) outer membrane of mitochondrion

71. Reduced coenzymes are regenerated in ETS by
(1) gain of protons
(2) loss of electrons
(3) addition of hydrogen
(4) gain of electrons.

72. Poisons like cyanides inhibit Na^+ efflux and K^+ influx. The effect is reversed by injection of ATP indicating that
(1) Na^+— K^+ pump operates in all cells
(2) ATP is carrier protein
(3) Energy for Na^+—K^+ pump come from ATP
(4) ATP is hydrolysed by ATPase to release energy

73. Proton channel of oxysome is located in
(1) F_0 (2) F_1 (3) F_4 (4) F_5

74. The first 5-C dicarboxylic acid in Krebs' cycle which is used in nitrogen metabolism is
(1) OAA (2) Citric acid
(3) α-ketoglutaric acid (4) Acetyl Co-A

75. In Krebs' cycle, the H^+ removed at succinate level is accepted by
(1) FAD (2) NAD
(3) ADP (4) FMN

76. Fructose-6-phosphate is changed to Fructose 1-6 biphosphate with the help of enzyme
(1) phosphoglycerate (2) enolase
(3) phosphofructokinase
(4) phosphatase

77. In ETC, ATP is not formed in which of the following steps
(1) FMN — UQ (2) Cyt c—cyt a
(3) Cyt b — cyt c (4) Cyt a — cyt a_3

78. Krebs' cycle is completed with the formation of
(1) citric acid (2) OAA
(3) succinic acid (4) malic acid

79. End product of oxidative phosphorylation is
(1) ATP (2) O_2
(3) $NADH_2$ (4) ATP & H_2O

*80. How many ATP are formed in ETS from reduced NAD generated in one turn cycle of Krebs' cycle ?
(1) 3 (2) 6 (3) 12 (4) 9

81. Krebs' cycle starts with reaction between
(1) OAA+Acetyl CoA
(2) OAA+Pyruvic acid
(3) Acetyl CoA+Citric acid
(4) OAA+Citric acid

82. ATP synthesis is endergonic process. Its mechanism of formation both in chloroplast and mitochondria is best explained by
(1) Lock and Key Theory of Fisher
(2) Chemiosmotic Theory of Mitchell
(3) Lipmann and Lohmann Theory
(4) Chemical coupling theory

83. What is the main feature of ~P bond in ATP ?
(1) 2 bonds having high energy
(2) 2 Molecules of phosphrous in ATP
(3) 3 atoms of high energy phosphate
(4) None of these

84. Which would be the last substrate to be used in respiration ?
(1) Fat (2) Protein
(3) Organic acid (4) starch

85. A mass of living cells are kept in a culture medium under anaerobic conditions. The cells were supplied with labelled C^{14} glucose. Pick up the true statement
(1) CO_2 will contain C^{14}
(2) cell would burst
(3) water will have radioactivity
(4) ATP will have radioactivity

86. Differences between photophosphorylation (PP) and oxidative phosphorylation (OP) is
(1) In PP it is synthesis of ATP while in OP it is of ADP

*80. One turn of Krebs Cycle produces 3 NADH. One NADH on oxidation produces 3 ATP. Therefore, one turn will produce 9 ATP.

(2) In PP, O_2 is evolved while in OP O_2 is used up
(3) Both can not take place in light
(4) PP occurs in green leaves while OP cannot occur in green leaves

*87. Which one is absent in erythrocytes ?
(1) Krebs' cycle (2) Enzymes
(3) EMP pathway (4) Hyaloplasm

88. Calorific value of carbohydrates, proteins & fats are
(1) 4 : 6 : 9 (2) 6 : 4 : 9
(3) 4 : 4 : 9 (4) 4 : 9 : 9

89. Which one of the following is the source of energy that produces the chemiosmotic gradient in mitochondria ?
(1) Electrons moving down the electron transport chain
(2) The production of NADH
(3) An ATP-dependent proton pump
(4) The components of the electron transport chain

90. When O_2 is not available to a muscle, NADH formed in glycolysis does not pass electrons to the ETC. Instead it passes them to
(1) Acetyl Co A (2) pyruvic acid
(3) fructose (4) ADP

*91. Number of oxygen atoms required for complete oxidation of one molecule of pyruvic acid
(1) 6 (2) 12 (3) 3 (4) 8

92. Cyanide kills the organisms/stop cell activity by
(1) reducing water potential
(2) decreasing diffusion of oxygen
(3) interfering in respiratory mechanism by preventing transfer of electron from copper of cyt a_3 to oxygen
(4) coagulating proteins of carriers in ETC

93. During oxidative phosphorylation, protons return to
(1) matrix from outside
(2) outside from matrix
(3) in both directions
(4) mitochondria to cytoplasm

94. The energy from electron transport is utilized in transporting proton (H^+) from
(1) matrix to outside (2) outside to matrix
(3) in both directions (4) none of these

95. Enzyme helping in oxidative decarboxylation of pyruvic acid is
(1) pyruvic kinase
(2) pyruvic dehydrogenase
(3) succinic dehydrogenase
(4) pyruvic oxidase

96. Glyceraldehyde phosphate is oxidised during glycolysis What happens to the hydrogen atom & the electrons that are removed during oxidation ?
(1) They reduce NAD^+
(2) They oxidise NAD^+
(3) They are transferred to pyruvic acid
(4) They are eliminated

97. In Which step, CO_2 is not released ?
(1) Glycolysis
(2) Lactic acid fermentation
(3) Oxidation of malic acid into OAA
(4) All of the above

98. General equation for aerobic respiration is
(1) $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
(2) $C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O+686$ Kcal
(3) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 2ATP$
(4) $C_{12}H_{22}O_{11}6O_2 \rightarrow 6CO_2+6H_2O+686$cal

99. Number of glucose molecules required to produce 38 ATP molecules under anaerobic condition by a yeast cell
(1) 2 (2) 1 (3) 19 (4) 38

100. One turn of Krebs' cycle produces
(1) 1 $FADH_2$, 1 NADH and 1 ATP
(2) 1 $FADH_2$, 2 NADH and 1 ATP
(3) 1 $FADH_2$, 3 NADH and 1 ATP
(4) 2 $FADH_2$, 2 NADH and 2 ATP

101. Excess of ATP inhibits which enzyme
(1) phosphofructokinase
(2) pyruvic dehydrogenase
(3) isomerase
(4) acomitase

102. Anaerobic respiration in animals produces
(1) CO_2 and H_2O
(2) C_2H_5OH and CO_2

*87. RBC takes energy by EMP pathway only. Krebs' cycle is absent.

*91. 1 molecule of glucose requires $6O_2$ for complete oxidation. 1 glucose produces 2 pyruvic acid molecules and therefore, 3 O_2 or 6 atoms of oxygen are required for 1 molecule of pyruvic acid.

(3) Lactic acid and H_2O
(4) Glucose and O_2

103. Choose the correct statement
(1) respiration is carried out by only leaf cells
(2) end product of anaerobic respiration is CO_2 + Pyruvic acid
(3) substrate level phosphorylation occurs when α-ketoglutaric acid changes to succinic acid
(4) dark respiration in plants occurs only in night

104. In alcoholic fermentation by yeasts, the $NADH_2$ produced during glycolysis is used to reduce
(1) Acetaldehyde to ethanol
(2) NADP to $NADPH_2$
(3) Pyruvic acid to lactic acid
(4) Lactic acid to pyrvic acid

*105. Maximum energy is obtained by the oxidation of
(1) glucose
(2) palmitic acid
(3) malic acid
(4) amino acid

106. Fats enter common pathway of respiration as
(1) DHAP and ketoglutarate
(2) Glyceraldehyde–3–phosphate and acetyl CoA
(3) Glycolic acid and acetyl CoA
(4) OAA and Glyceric acid

107. If it is calculated that less than 5% of the energy of glucose is recovered as ATP in glycolysis, the remaining energy is left in
(1) CO_2 and NADPH
(2) Pyruvate and $FADH_2$
(3) Pyruvate and NADH
(4) CO_2 and $NADH_2$

108. Why the usual RQ for humans lies between 0.7 and 1.0 because
(1) they respire fat and protein
(2) they utilize and respire carbohydrate and fat
(3) they respire carbohydrate and proteins
(4) they respire proteins and carbohydrate

109. How many molecules of NADH + H^+ are left at the end of anaerobic respiration
(1) 2
(2) 4
(3) 6
(4) 0

110. In Beta oxidation, ATPs are produced by
(1) Flavin & Acetyl CoA
(2) Fatty acid
(3) NADH
(4) NAD^+

*111. A business man of 70 kg weight requires 2800 kcal energy daily. How many glucose molecules and ATP molecules does he require to produce this much energy ?
(1) 20 molecules of glucose and 384 molecules of ATP
(2) 11 molecules of glucose and 380 molecules of ATP
(3) 1 Molecule of glucose and 38 molecules of ATP
(4) 6 molecules of glucose and 584 molecules of ATP

112. Which intermediate product is found in all three of the following process
(a) anaerobic respiration
(b) aerobic respiration
(c) photosynthesis
(1) succinic acid
(2) lactic acid
(3) Ribulose diphosphate
(4) Phosphoglyceric acid

113. In glycolysis, enzyme enolase produces
(1) PGA
(2) PEP
(3) PGAL
(4) Pyruvate

114. Number of carbon atoms available in Acetyl CoA is
(1) 6
(2) 4
(3) 3
(4) 2

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*105. A 2C compound forms one molecule of acetyl CoA. one mole of acetyl CoA yields 12 ATP through Krebs' cycle. A 18C compound like stearic acid ($C_{18}H_{36}O_2$) yields 9 acetyl CoA + 8 molecules, one each of $NADH_2$ + $FADH_2$ through b-oxidation. $NADH_2$ on oxidation produces 3ATP and $FADH_2$ produces 2ATP *i.e.*, total 3 + 2 = 5 . Thus 18 C compound will produce 9 Acetyl CoA (9 × 12 ATP) + 8 mols one each of $NADH_2$ + $FADH_2$ (8 × 5 ATP) = 108 + 40 = 148 ATP. Two ATP are used up and, therefore, net gain = 146. Similarily a 16C compound (*e.g.*, palmitic acid, $C_{16}H_{32}O_2$) will produce 8 Acetyl CoA (8 × 12 = 96 ATP) + 7 molecules, one each of $NADH_2$ and $FADH_2$ (7 × 5 = 35 ATP) *i.e.*, 96 + 35 = 131 ATP. 2 ATP used up and therefore, net ATP = 131 – 2 = 129.

*111. One molecule of glucose yields 686 Kcal of which only 262. 8 Kcal (= 36 ATP) is usable and rest is lost as heat. 1 ATP yields 7.3 Kcal and accordingly (1) number of glucose for 2800 Kcal energy will be $\frac{2800}{262.8}$ = 11. (ii) number of ATP will be $\frac{2800}{7.3}$ = 384.

115. Which can readily respire without oxygen ?
(1) *Anabaena* (2) *Saccharomyces*
(3) Mushroom (4) Fish

116. Cytochrome is a component of ETC in mitochondria/chloroplast, acting as electron acceptor. It is a
(1) glycoprotein
(2) lipid
(3) Ca^{2+} containing metallo flavoprotein
(4) Fe^{+++} containing prophyrin pigment protein

117. Match the biochemical processes given under column I with their respective cellular locations given under column II. From the answers, choose the one which gives the correct combination of alphabets

	Column - I	Column - II
A	Krebs cycle	–
B	Glycolysis	J Grana
C	Link Reaction	K Mitochondrial matrix
		L Cytoplasm

(1) A = L, B = K, C = L
(2) A = K, B = L, C = J
(3) A = K, B = L, C = K
(4) A = L, B = K, C = J

118. First oxidative decarboxylation during aerobic respiration occur in
(1) cytoplasm
(2) mitochondrial inner space
(3) mitochondrial outer space
(4) mitochondrial matrix.

119. One mole of glucose on complete oxidation in aerobic respiration yields ?
(1) 2870 KJ (2) 5000 KJ
(3) 686 KJ (4) 1870 KJ

120. Protons taking part in oxidative phosphorylation enter mitochondrion as
(1) OAA (2) Acetyl~CoA
(3) Pyruvic acid (4) Acetaldehyde

121. How many complexes are found in ETS in inner membrane of mitochondria ?
(1) 2 (2) 3 (3) 4 (4) 5

122. Complex V in ETS consists of
(1) $F_0 — F_1$ (2) ATP synthase
(3) Both correct
(4) Cytochrome C oxidase

123. Two names refer to one and the same thing
(1) Citric acid cycle and Calvin cycle
(2) Krebs' cycle and Calvin cycle
(3) TCA cycle and urea cycle
(4) Tricarboxylic acid cycle and citric acid cycle

124. ETC is also called
(1) photooxidation
(2) oxidative phosphorylation
(3) cyclic phosphorylation
(4) noncyclic phosphorylation

125. Which one of the following enzymes is absent in electron transport system ?
(1) NADH dehydrogenase
(2) Cytochrome C-oxidase
(3) Succinate Q-reductase
(4) G_6 phosphate dehydrogenase

126. Which one of the following enzymes of respiratory pathway has the coenzyme FAD^+ linked with it ?
(1) Citric acid synthetase
(2) Fumerase
(3) Isocitric dehydrogenase
(4) Succinic acid dehydrogenase

127. During the reaction $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ which compound is reduced ?
(1) Oxygen (2) Carbon dioxide
(3) Glucose (4) Water

128. Glyceraldehyde-3-phosphate is
(1) produced from glucose during glycolysis
(2) part of PS-I
(3) produced from pyruvate before entering the mitochondria
(4) an amino acid used for making protein

129. Dough kept overnight in warm weather becomes soft and spongy because of
(1) absorption of carbon dioxide from atmosphere
(2) fermentation
(3) cohesion (4) osmosis

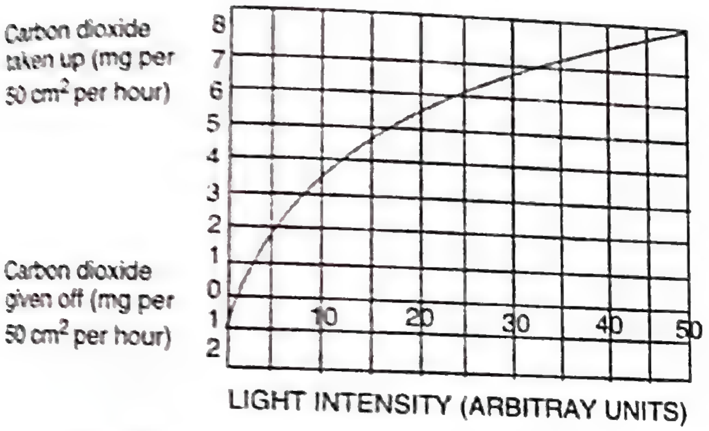
130. Fatty acids enter cellular respiration as
(1) one carbon fragment
(2) two carbon fragments
(3) three carbon fragments
(4) long chain of 16 to 20 carbon atoms

131. In glycolysis, during oxidation, electron's are removed by
(1) ATP (2) GAP
(3) NAD^+ (4) molecular oxygen

132. The production of ATP by oxidative phosphorylation is driven by energy from
(1) coenzyme A
(2) cytochromes
(3) formation of NADH
(4) diffusion of protons from inter membrane space to the matrix of mitochondrion

133. Both mitochondria and chloroplasts
(1) use a hydrogen ion (proton) gradient to produce ATP
(2) obtain electron from water
(3) reduce NAD^+, forming NADP
(4) release oxygen as a by product

134. The graph shows the relation between light intensity and the giving off and taking up of carbon dioxide by the leaves of a plant. Why is most carbon dioxide given off when the light intensity is zero units ?
(1) because it is just the start of the experiment
(2) only respiration is taking place at this intensity of light

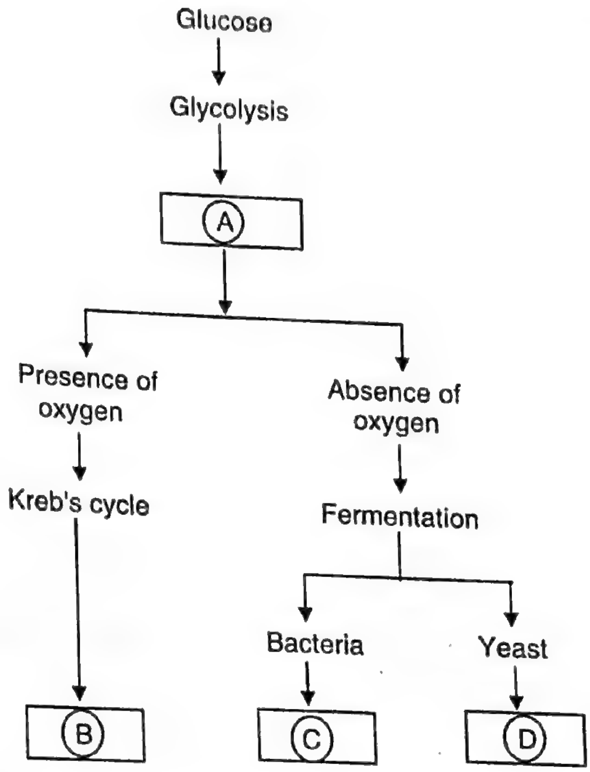


(3) the rate of photosynthesis is equivalent to the rate of respiration
(4) the rate of photosynthesis is more than the rate of respiration

135. Chemiosmosis is
(1) synthesis of ATP using the driving force of proton gradient across mitochondrial inner membrane
(2) synthesis of ATP by the discharge of chemical potential created by protons and hydroxyl ions on different sides of a membrane
(3) chemical synthesis of ATP by taking energy rich bond from a respiratory substrate
(4) both (1) and (2)

136. Which of the following processes make direct use of oxygen ?
(1) Glycolysis (2) Fermentation
(3) Electron transport
(4) Krebs citric acid cycle
(5) Hydrolysis

137. The following is a simplified scheme showing the fate of glucose during aerobic and anaerobic respiration. Identify the end products that are formed at stages indicates as A, B, C, and D. Identify the correct option from those given below.



(1) A = carbon dioxide and water, B = pyruvic acid, C = ethyl alcohol and carbon dioxide, D = lactic acid
(2) A = pyruvic acid, B = carbon dioxide and water, C = lactic acid, D = ethyl alcohol and carbon dioxide
(3) A = pyruvic acid, B = carbon dioxide and water, C = ethyl alcohol and carbon dioxide, D = lactic acid
(4) A = pyruvic acid, B = ethyl alcohol and carbon dioxide, C = lactic acid, D = carbon dioxide and water *(Karnataka 2006)*

138. Ganong's respirometer (respiroscope) is used to demonstrate rate of respiration and
(1) evolution of O_2 in photosynthesis
(2) evolution of CO_2 in fermentation
(3) evolution of CO_2 in aerobic respiration
(4) evolution of heat in aerobic respiration

3. α–ketoglutarate dehydrogenase
4. Isocitric dehydrogenase

What is the correct order in which the above enzymes catalyze the reaction in Kreb's cycle?

(1) 1 – 2 – 3 – 4 (2) 2 – 4 – 1 – 3
(3) 3 – 2 – 4 – 1 (4) 2 – 4 – 3 – 1

160. Which one of the following is the correct sequence of electron transport in Mitochondria?

(1) NADH → UQ → Cyt b → Cyt c_1 → Cyt c → Cyt a → Cyt a_3 → O_2
(2) NADH → Cyt a → Cyt a_3 → UQ → Cyt b → Cyt c_1 → Cyt c → O_2
(3) NADH → UQ → Cyt b → Cyt a → Cyt a_3 → Cyt c → Cytc_1 → O_2
(4) NADH → Cyt b → Cyt c_1 → Cyt c → UQ → Cyt a → Cyt a_3 → O_2

161. Consider the following enzymes of glycolytic pathway

1. Glyceraldehyde-3 phosphate dehydrogenase
2. Enolase
3. Pyruvate kinase
4. Phosphoglycerate kinase

The correct order in which they appear in the pathway is

(1) 2, 1, 4, 3 (2) 3, 2, 1, 4
(3) 4, 3, 2, 1 (4) 1, 4, 2, 3

162. Consider the following intermediates formed during Krebs cycle

1. α-ketoglutarate 2. Isocitrate
3. Succinate 4. Malate
5. Fumerates

The correct sequences in which the above intermediates are formed is –

(1) 1, 2, 4, 3, 5 (2) 2, 1, 5, 4, 3
(3) 3, 1, 2, 5, 4 (4) 2, 1, 3, 5, 4

163. Consider the following statements in Citric Acid Cycle

1. The generation of ATP is done at two steps
2. NAD is reduced to NADH at two steps
3. FAD is reduced to $FADH_2$, at one step

Which of the statements given above is/are correct?

(1) 1 and 2 only (2) 3 only
(3) 1 and 3 only (4) 1, 2 and 3

164. Consider the following

1. Two lactate molecules
2. Two Pyruvate molecules
3. Two ATP molecules
4. Two NADH + $2H^+$

Which of the above are the end products of aerobic glycolysis?

(1) 1 and 4 (2) 1 and 3
(3) 1, 3 and 4 (4) 2, 3 and 4

165. Consider the following:

1. Succinate 2. Succinyl CoA
3. NADH + H^+ 4. CO_2

When α–ketoglutarate dehydrogenase enzyme acts on α–ketoglutarate, which of the above are produced?

(1) 1 and 2 only (2) 1 and 3 only
(3) 1, 3 and 4 (4) 2, 3 and 4

166. Which of the following serves as the breakdown site for beta-oxidation?

(1) Cytosol
(2) Extramembrane space of mitochondria
(3) Matrix of mitochondria
(4) Smooth endoplasmic reticulum

167. The pyruvate dehydrogenase complex catalyzes the conversion of pyruvate to acetyl CoA. Which of the following changes will increase the metabolic consumption of pyruvate?

(1) High levels of ATP
(2) High levels of NADH
(3) Low levels of glucose
(4) Low levels of Acetyl CoA

168. What is the total number of $FADH_2$ molecules produced by glycolysis and the citric acid cycle (two turns of the cycle)?

(1) 1 mole at Succinate to Fumarate conversion
(2) 2 moles at Succinate to Fumarate conversion
(3) 3 moles at Malate to Oxaloacetate conversion
(4) 4 moles at Malate to Oxaloacetate conversion

169. During carbohydrate metabolism, NADH is produced in which of the following location(s)?

I. Cytosol
II. Mitochondrial matrix
III. Nucleus

(1) I only (2) II only
(3) I and II only (4) I, II, and III

170. When examining the TCA cycle, alpha keto-glutarate dehydrogenase complex requires the set of cofactors as which of the following?
(1) Citrate synthase
(2) Cis-aconitate
(3) Pyruvate dehydrogenase
(4) Fumarate

171. For each acetyl Co-A oxidized by the citric acid cycle, what is the energy gain?
(1) Two molecules of NADH, one $FADH_2$ and one nucleoside triphosphate
(2) Three molecules of NADH, one $FADH_2$ and one nucleoside triphosphate
(3) Two molecules of NADH, one $FADH_2$ and two nucleoside triphosphate
(4) Three molecules of NADH, one $FADH_2$ and two nucleoside triphosphate

172. True about citric acid cycle
(1) 8 ATP molecules are produced
(2) Fat soluble vitamins are required
(3) Involved in fatty acid synthesis
(4) O_2 is consumed

173. A person with a coenzyme Q deficiency will have a defect in oxidative phosphorylation. Which of the following would be expected in this person?
(1) accumulation of glucose
(2) accumulation of lactate
(3) high levels of ATP
(4) fructose deficiency

174. Fluoroacetate, a potent toxin extracted from plants, is converted to fluorocitrate, which is a strong inhibitor of the TCA cycle. Which of the following would be expected in a person exposed to fluoroacetate?
(1) an increase in intracellular levels of ATP
(2) an increase in intracellular levels of glucose
(3) a decrease in levels of ethanol
(4) a decrease in the function of the electron transport chain

175. Aerobic respiratory pathway is appropriately termed
(1) Amphibolic (2) Anabolic
(3) Catabolic (4) Parabolic

176. Which of the following membrane-bound complexes in mitochondria is not a proton pump?
(1) NADH dehydrogenase
(2) Succinate dehydrogenase
(3) Cytochrome bc_1
(4) Cytochrome c oxidase
([illegible])

177. The citric acid cycle is [illegible] step in carbohydrate metabolism
(1) First (2) Second
(3) Third (4) Fourth
([illegible])

178. Respiratory quotient (R.Q.) for a fatty acid, Tripalmitin is
(1) 0.9 (2) 1.4 (3) 1.0 (4) 0.7
(HP PMT 2011)

179. In mitochondria, protons accumulate in the
(1) Outer membrane
(2) Inner membrane
(3) Intermembrane space
(4) Matrix
(CBSE Main 2011)

180. The number of ATP produced when a molecule of glucose undergoes fermentation is
(1) 4 (2) 36 (3) 2 (4) 38
(Karnataka CET 2011, J & K 2011)

181. In mitochondrial electron transport system, for every two pairs of electrons that pass from NADH molecules through a sequential series of cytochrome enzymes to molecular oxygen generate
(1) 3 ATP (2) 4 ATP
(3) 6 ATP (4) 2 ATP
(AMU Medical 2011)

182. Which of these steps in Kreb's cycle indicates substrate level phosphorylation ?
(1) Conversion of succinic acid to α-ketoglutaric acid
(2) Conversion of succinic acid to malic acid
(3) Conversion of succinyl CoA to succinic acid
(4) Conversion of citric acid to α-ketoglutaric acid
(5) conversion of malic acid to oxaloacetic acid
(Kerala PMT 2011)

183. EMP pathway occurs in the
(1) Cytoplasm (2) Mitochondrion
(3) Chloroplast (4) Lysosome
(HP PMT 2011)

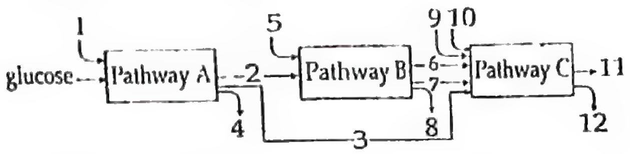
184. When proteins are respiratory substrate, RQ will be
(1) 0.7 (2) 1.0
(3) 0.9 (4) More than one
(HP PMT 2011)

185. Anaerobic respiration in yeast yields
(1) Ethanol and CO_2
(2) Lactic acid and O_2
(3) CO_2 and water
(4) Pyruvic acid and O_2 *(HP PMT 2012)*

*186. Arrange the following compounds of Krebs cycle in an ascending order with respect to the number of carbon atoms they possess
(A) Succinic acid (B) Acetyl Co – A
(C) *a* - Ketoglutaric acid
(D) Citric acid
(1) A – D – C – B (2) C – A – D – B
(3) B – A – C – D (4) D – C – B – A
(HP PMT 2012)

187. Which of the metabolites is common to respiration-mediated breakdown of fats, carbohydrates and proteins?
(1) Pyruvic acid (2) Acetyl CoA
(3) Glucose – 6 –phosphate
(4) Fructose 1, 6 –bisphosphate
(NEET 2013)

*188. The three boxes in this diagram represent the three major biosynthetic pathways in aerobic respiration. Arrows represent net reactants or products.



Arrows numbered 4, 8 and 12 can all be
(1) H_2O (2) FAD^+ or $FADH_2$
(3) NADH (4) ATP *(NEET 2013)*

189. In which one of the following processes CO_2 is not released?
(1) Lactate fermentation
(2) Aerobic respiration in plants
(3) Aerobic respiration in animals
(4) Alcoholic fermentation *(AIPMT 2014)*

190. Last electron acceptor in ETS is
(1) O_2 (2) Water
(3) Cytockrome C (4) Cytochrome a_3

191. Which of the following biomolecules is common to respiration-mediated breakdown of fats, carbohydrates and proteins?
(1) Glucose-6-phosphate
(2) Fructose 1, 6-bisphosphate
(3) Pyruvic acid
(4) Acetyl CoA *(NEET-2-2016)*

192. Oxidative phosphorylation is
(1) formation of ATP by transfer of phosphate group from a substrate to ADP
(2) oxidation of phosphate group in ATP
(3) addition of phosphate group to ATP
(4) formation of ATP by energy released from electrons removed during substrate oxidation *(NEET-2-2016)*

193. Which of the following cell organelles is responsible for extracting energy from carbohydrates to form ATP?
(1) Lysosome (2) Ribosome
(3) Chloroplast (4) Mitochondrion
(NEET 2017)

194. Which statement is wrong for Krebs' cycle?
(1) There are three points in the cycle where NAD^+ is reduced to $NADH+H^+$
(2) There is one point in the cycle where FAD^+ is reduced to $FADH_2$
(3) During conversion of succinyl CoA to succinic acid, a molecule of GTP is synthesised
(4) The cycle starts with condensation of acetyl group (acetyl CoA) with pyruvic acid to yield citric acid
(NEET 2017)

*186. Acetyl Co – A is a 2-carbon compound; Succinic acid is a 4-carbon compound; a-ketoglutaric acid is a 5-carbon compound while citric acid is a 6-carbon compound.
*188. Pathway A represents Glycolysis; B is Kreb's cycle and C is ETC.
- ATP is produced in all these three pathways (represented by 4, 8, 12).
- NADH is produced in pathway A and B, not in C
- $FADH_2$ is produced only in pathway B.
- H_2O is produced in A & C, not in Kreb's cycle.

ANSWERS

1. (4)	2. (2)	3. (2)	4. (3)	5. (1)	6. (3)	7. (4)	8. (2)	9. (2)	10. (3)
11. (3)	12. (1)	13. (3)	14. (1)	15. (1)	16. (2)	17. (3)	18. (1)	19. (2)	20. (2)
21. (1)	22. (1)	23. (4)	24. (1)	25. (3)	26. (4)	27. (3)	28. (2)	29. (1)	30. (2)
31. (3)	32. (4)	33. (1)	34. (4)	35. (2)	36. (1)	37. (1)	38. (1)	39. (1)	40. (1)
41. (2)	42. (1)	43. (2)	44. (2)	45. (3)	46. (3)	47. (4)	48. (2)	49. (1)	50. (2)
51. (3)	52. (2)	53. (3)	54. (1)	55. (1)	56. (2)	57. (2)	58. (2)	59. (3)	60. (4)
61. (1)	62. (3)	63. (3)	64. (2)	65. (2)	66. (1)	67. (2)	68. (3)	69. (3)	70. (2)
71. (2)	72. (3)	73. (1)	74. (3)	75. (1)	76. (3)	77. (2)	78. (2)	79. (4)	80. (4)
81. (1)	82. (2)	83. (1)	84. (2)	85. (1)	86. (2)	87. (1)	88. (3)	89. (1)	90. (2)
91. (1)	92. (3)	93. (1)	94. (1)	95. (2)	96. (1)	97. (4)	98. (2)	99. (3)	100. (3)
101. (1)	102. (3)	103. (3)	104. (1)	105. (2)	106. (2)	107. (3)	108. (2)	109. (4)	110. (2)
111. (2)	112. (4)	113. (2)	114. (4)	115. (2)	116. (4)	117. (3)	118. (4)	119. (1)	120. (3)
121. (4)	122. (3)	123. (4)	124. (2)	125. (4)	126. (4)	127. (1)	128. (1)	129. (2)	130. (2)
131. (3)	132. (4)	133. (1)	134. (2)	135. (4)	136. (3)	137. (2)	138. (3)	139. (1)	140. (2)
141. (1)	142. (1)	143. (1)	144. (2)	145. (2)	146. (3)	147. (1)	148. (2)	149. (3)	150. (2)
151. (4)	152. (4)	153. (2)	154. (2)	155. (3)	156. (4)	157. (2)	158. (4)	159. (4)	160. (1)
161. (4)	162. (4)	163. (2)	164. (4)	165. (4)	166. (3)	167. (4)	168. (2)	169. (3)	170. (3)
171. (2)	172. (3)	173. (2)	174. (4)	175. (1)	176. (2)	177. (3)	178. (4)	179. (3)	180. (3)
181. (3)	182. (3)	183. (1)	184. (3)	185. (1)	186. (3)	187. (2)	188. (4)	189. (1)	190. (1)
191. (4)	192. (4)	193. (4)	194. (4)						

15 PLANT GROWTH AND DEVELOPMENT

Seed germinates to produce seedling. Seedling grows first into a juvenile plant which develops only vegetative organs. Later on it begins to produce flowers, fruits and seeds. Unlike animals, plants do not stop growing after reaching maturity. They continue to grow and bear new roots, leaves, branches, flowers, etc. While roots, stems and their branches have **indefinite growth**, other organs like leaves, flowers and fruits show limited or **definite growth**. They appear and fall off periodically and sometimes repeatedly. There is a highly ordered succession of events. A plant consists of billions of cells arranged in specific tissues and organs. All of them are descendents of a single celled zygote. However, by their specific differentiation and location in the plant they come to have different functions. As a result complex organisation is formed that produces roots, leaves, branches, flowers, fruits and seeds. After a period of growth, differentiation and development, each plant dies. There are a number of **intrinsic** (internal) and **extrinsic** (external) factors which control various development processes.

Seed Germination (Fig. 15.1)

Seed germination is sprouting of seed due to growth and development of its embryo to form a seedling. A seed can germinate only when it has favourable internal and external conditions.

Favourable Internal Conditions. (i) Nondormancy or completion of dormancy. (ii) Viability, *i.e.*, the embryo of the seed is alive and capable of resuming growth. (iii) Sufficient storage food. (iv) Maturation of embryo.

Favourable External Conditions. They are availability of water, oxygen, optimum temperature (25°–35°C), in some cases light and particular *p*H. In the absence of favourable external or exogenous conditions, a nondormant seed is said to be in **quiescent state** or quiescence.

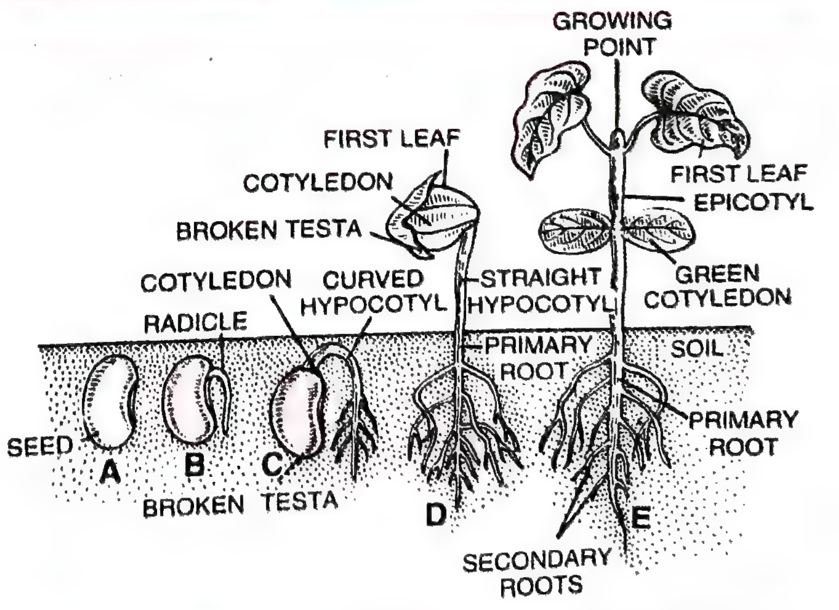


Fig. 15.1. Germination and development of Bean seedling.

In the presence of favourable external conditions a viable nondormant seed imbibes water through micropyle and seed coat. The seed coat softens. The seed kernel swells up and ruptures the softened seed coat. Imbibition of water is the **first step of seed germination.** Embryo

becomes active. If produces hormones and enzymes for hydrolysis of stored polysaccharides, proteins and lipids. Soluble solutes are formed. They develop osmotic concentration for normal absorption of water. Respiration is initially anaerobic. Soon it becomes aerobic. Rate of respiration also increases. The mobilised nutrients reach the embryo cells. They grow, divide and differentiate.

Radicle grows, breaks the seed coat and comes out to form the first root. Emergence of radicle is the **first sign of seed germination.** There is now increased absorption of water. Rate of embryo growth increases. Plumule grows to produce the shoot system. It converts the seed into seedling which is capable of manufacturing its own food. Growth of plumule is accompanied by rapid growth of either hypocotyl or epicotyl. Cotyledons remain inside the soil when epicotyl grows. It is called **hypogeal germination** (*e.g.*, Pea). Cotyledons come out of the soil alongwith enclosed plumule when hypocotyl grows. It is known as **epigeal germination** (*e.g.*, Bean).

Vivipary

It is germination of seed while it is attached to the parent plant and is being nourished by it. Vivipary occurs in **mangrove plants** (*e.g.*, *Rhizophora, Sonneratia*) which grow in saline marshes along the sea shore. Seeds cannot germinate in saline marshes due to high salinity. Such seeds do not undergo dormancy. While attached to the plant, the embryo of the seeds grows out to form a seedling with long hypocotyl. Being heavy, the seedling falls down in the saline marsh in vertical position with plumule remaining out. The radicle end soon develops lateral roots for proper anchorage of the seedling.

GROWTH

Growth is often referred to as an increase in size or weight (fresh or dry) of a cell, organ or organism. However, increase in size can occur without growth as absorption of water by a flaccid cell or regaining of turgidity by a wilted leaf. Similarly, during germination of a seed there is an actual fall of dry weight though the size and fresh weight increase. Therefore, *growth is defined as a permanent or irreversible increase in dry weight, size, mass or volume of a cell, organ or organism*. Growth in living beings is **intrinsic** or internal. It is in contrast to **extrinsic** growth observed in nonliving objects like enlargement of a stone or swelling of a piece of wood placed in water. In living beings irreversible increase in size, mass or volume is an external manifestation of growth. It is also called **apparent growth**. Real growth consists of formation of new protoplasm. This is possible only when the rate of synthesis of new proteins, carbohydrates and other protoplasmic constituents is higher than the rate of their breakdown. It occurs at the expense of energy. In plants, growth is accomplished by cell division, increase in cell number and cell enlargement. Therefore, growth is a **quantitative phenomenon**. It can be measured in relation to time.

Plant Growth is Generally Indeterminate. In lower plants, growth is diffused as every cell can divide and enlarge. Higher plants possess specific areas which take part in the formation of new cells. These areas are called **meristems**. Meristems are of three types— apical, intercalary and lateral. On account of the presence of meristems or growing points, plant growth is **localised**. The body of plants is built on a **modular fashion** (with discrete units or stages) where structure is never complete because the tips (with apical meristem) are **open ended**— always growing and forming new organs to replace the older or senescent ones.

Cells of the meristematic region have the capacity to divide and self perpetuate. They produce cells which lose the capacity to divide and enter G_0 phase for undergoing differ-

entiation to form particular tissues and organs. Root apical meristem (RAM) and shoot apical meristem (SAM) contribute cells for elongation of plant parallel to its axis. It is **primary growth**. Another meristem contributing to primary growth is intercalary meristem located above the nodes in grasses and related plants. In some cases, it is functional throughout the life of the plant. However, intercalary meristem present in leaf and flower primordia has a short period of activity. It is consumed in the formation of the organs. The meristem which is consumed in the formation of an organ is called **determinate meristem.** The meristem which continues its activity throughout life of the plant is called **indeterminate meristem**. Root apical meristem, shoot apical meristem, intercalary meristem (*e.g.*, grass) and lateral meristems are all indeterminate meristems. Lateral meristems contribute tissues for growth in girth. It is **secondary growth**. Secondary growth occurs in dicots and gymnosperms. There are two types of lateral meristems which contribute to secondary growth, **vascular cambium** (forms secondary xylem and secondary phloem) and **cork cambium** (forms cork and secondary cortex).

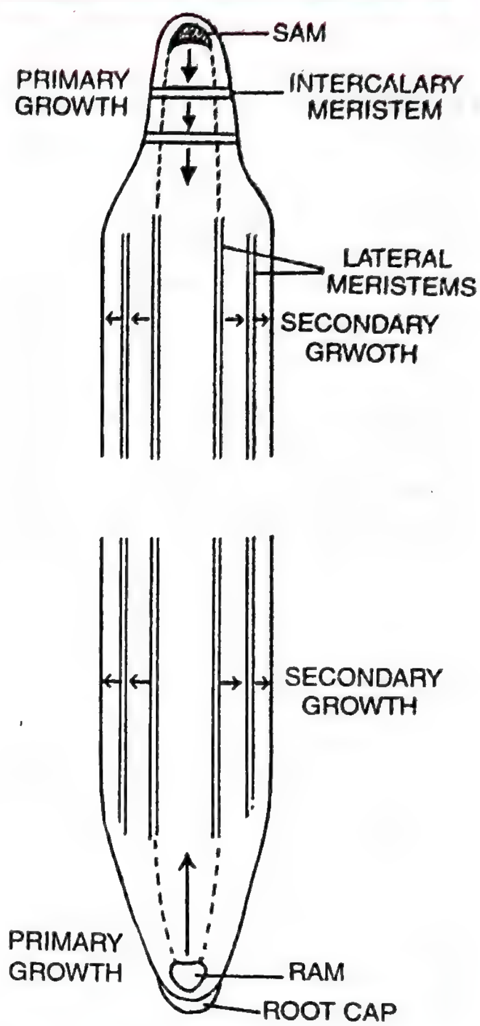


Fig. 15.2. Location of meristems and direction of growth by them.

Growth is Measurable

At the cellular level growth is due to increase in amount of protoplasm. However, it is difficult to measure increase in protoplasm. Increase in protoplasm leads to increase in cell, cell number and cell size. This fact is used in calculating growth which, therefore, is a quantitative or measurable phenomenon. The parameters used for measuring growth are increase in fresh weight, dry weight, length, area, volume and cell number. At the cellular level, growth occurs at a tremendous pace. A single cell of root meristem of Maize produces more than 17,500 new cells every hour. In Watermelon, a newly formed cell increases in size upto 3, 50,000 times during its enlargement. Both increase in cell number and cell size constitute the basis of growth. However, all structures do not show these parameters. A pollen tube grows only in length while growth of a dorsiventral leaf is measurable as increase in area. Rate of growth is growth per unit time. Rate of plant growth is slow in early stages. It is called lag phase. It then increases rapidly during exponential phase followed by slowing down and then becoming stationary (for organs of limited growth) or steady (for organs of unlimited growth). The last phase is due to limitation of nutrients.

Phases of Growth

Plant growth takes place in three steps or phases— formative, enlargement and differentiation.

1. **Formative Phase**. It is also called the phase of **cell formation** or **cell division**. It occurs at root apex, shoot apex and other regions having meristematic tissue. New cells are produced by mitotic divisions of the meristematic cells. The meristematic cells have thin cellulose walls, dense protoplasm and large nucleus. Plasmodesmal connections occur abundantly amongst the meristematic cells. Mitosis adds new cells to the body. The rate of mitosis

is very high. Apical meristem of Maize root adds some 17,500 new cells every hour. All the cells are genetically similar because in mitosis the chromosomes are replicated and divided equally both quantitatively as well as qualitatively. Mitosis is, therefore, also called **somatic cell division**. In higher plants formative phase occurs in meristems or growing points. As the formation of new cells requires intense biosynthetic activity, the rate of respiration in the cells of formative phase is very high. Due to cell divisions the growing points show some increase in their size.

2. **Phase of Enlargement**. The newly formed cells, produced in the formative phase, undergo enlargement. Cell walls of the enlarging cell show plastic extension through enzymatic loosening of microfibrils and deposition of new materials (intussusception). The enlarging cell also develops a central vacuole. Growth due to cell enlargement is very high. Cells in Watermelon fruit increase upto 3,50,000 times. Rate of respiration is high but less than that of the cells in the formative phase. The phase is found just behind the growing points and is mainly responsible for growth of plant parts.

Cell enlargement may occur in all directions as in isodiametric parenchymatous cells. In many parts cell enlargement takes place prominently in the linear direction so much so that this phase is also called **phase of cell elongation**. Maximum elongation occurs in conducting tissues and fibres.

3. **Phase of Differentiation or Maturation**. The enlarged cells develop into special or particular type of cells by undergoing structural and physiological differentiation. Through structural differentiation a cell attains a particular shape, size, thickening and internal constitution. In physiological differentiation a cell takes up a particular function, *e.g.*, absorption by root hair, transfer of metabolites by transfer cells, phytosynthesis by mesophyll cells, conduction by sieve tube cells, tracheids and vessels. Both structural and physiological differentiation produce various tissue and cell types. The diverse cell types observed in root are epidermis, cortex, vascular tissues, etc.

Experiment 1. To Study Phases of Growth (Fig.15.3)

Apparatus. Seeds of Pea or Bean, moist saw dust, water, petri dish, blotting paper, water proof ink, pen, scale.

Working. Germinate a few seeds of Pea or Bean in moist saw dust. Pick up a couple of seedlings with straight radicle of 2–3 cm length. Wash the seedlings. Blot the surface water. Mark the radicles from tip to base with 10–15 points at intervals of 2 mm with the help of water proof or India ink. As soon as the ink dries up, place the seedlings on moist blotting paper in a petri dish. Allow the seedling to grow for 1–2 days. Measure the intervals between the marks.

Results. Depending upon the distance between successive marks four regions can be noted in the growing radicle. The first lies at its tip and has little growth. It is the region of **cell formation**. The second part shows the maximum elongation. It represents the region of **cell elongation**. The third zone has lesser elongation and is region of **cell differentiation**. The last part of the root is the region of **mature cells** where growth has stopped.

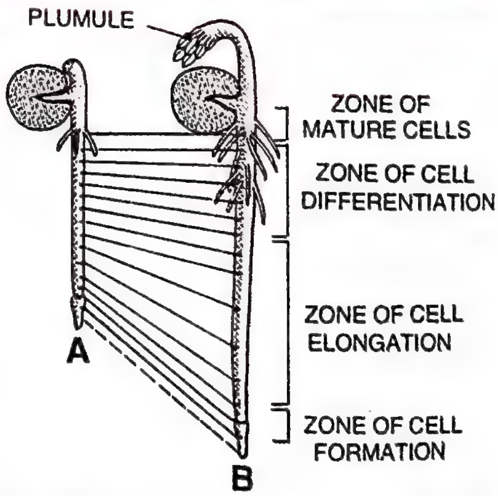


Fig. 15.3. Regions or phases of growth in root. A, marked radicle of the seedling at the beginning of experiment. B, marked radicle after 48 hours.

Growth Curve (Fig. 15.4)

It is the graphic representation of the total growth against time. The period or time, in which growth takes place, has been called **grand period of growth** by Sachs (1873). The rate of growth is not uniform during the grand period of growth. If total growth is plotted against time, an S-shaped or **sigmoid curve** is obtained. It consists of four parts — lag

phase, log phase (exponential phase), phase of diminishing growth and stationary phase (steady growth for organs or organisms of indefinite growth). Growth is slow in the lag phase, rapid during log or exponential phase, slow again during the phase of diminishing growth. Growth stops completely during the stationary phase. The various parts of growth curve correspond respectively to formative phase, phase of enlargement, phase of differentiation and mature state. Log phase is also called grand phase of growth. Sometimes, the rate of maximum growth of the log phase is maintained for some time. It is then known as **linear phase**. It appears as an upright line in growth curve.

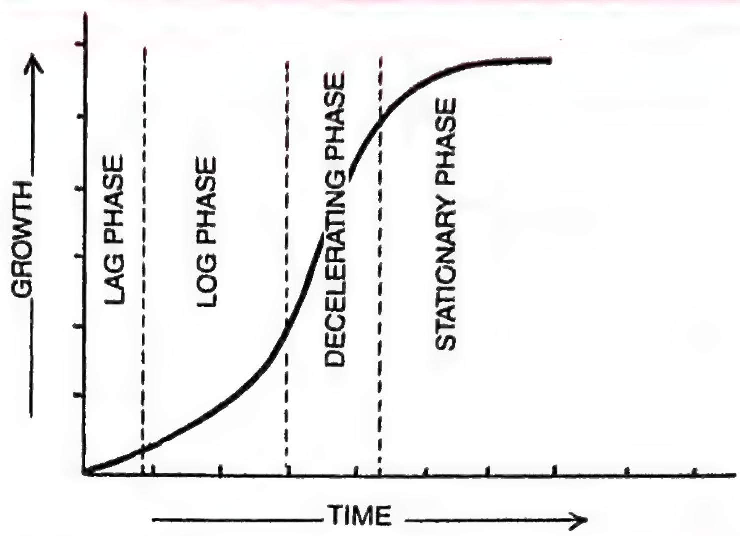


Fig. 15.4. Growth curve.

Measurement of Growth

Growth is measured through measuring (i) Increase in length, *e.g.*, stem, root, pollen tube. (ii) Increase in volume, *e.g.*, fruits. (iii) Increase in area, *e.g.*, leaves. (iv) Increase in diameter, *e.g.*, tree trunks, fruits. (v) Increase in fresh or dry weight. The various modes of measuring increase in length are :

1. **Direct Method.** Growth in length is measured at intervals of a few days by means of a scale. This is not much used, as in this case, growth over short periods cannot be measured.

2. **Horizontal or Travelling Microscope** (Fig. 15.5). It is a device for measuring growth more accurately than by means of a scale. A point is marked very near the tip of growing shoot by means of India ink. The horizontal or travelling microscope is focussed over this point. After a definite interval the marked point is observed under this microscope. It has to be raised for the same because due to growth the point on the shoot rises above the previous level. The distance, through which the microscope is raised, is a measure for the growth in length of the shoot during the interval.

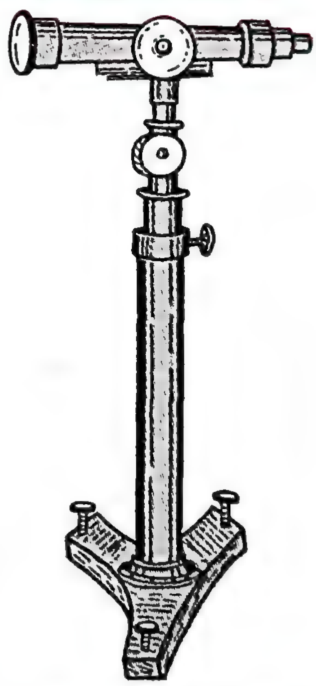


Fig. 15.5. Horizontal microscope.

3. **Arc or Lever Auxanometer.** It consists of a pulley which is attached to a pointer or large needle. The pointer has two unequal arms. The long arm can move over a graduated arc. The short arm possesses an adjustable large screw by which the weight of the pointer can be adjusted so that the long arm can move freely over the arc upside downwards. Arc auxanometer magnifies growth. The magnification is equal to the length of the long arm as measured from the centre of the pulley, divided by the radius of the pulley.

Unspun silken thread is tied to the stem tip of the plant, the shoot growth of which is to be measured. The other end of the thread is tied to a small weight. Pass the thread over the pulley so that the small weight hangs down freely (Fig. 15.6). The small weight keeps the thread stretched. It also helps the pulley to move alongwith its movement. As the stem

grows in length, the small weight moves downwardly. The pulley and the pointer also move. The distance through which the pointer moves is read on the graduated arc.

4. **Automatic Auxanometer** (Pfeffer). It consists of a double or compound pulley, a revolving cylinder with a smoked paper and a pointer. The revolving cylinder can register growth on a smoked paper with the help of the pointer. The double pulley magnifies growth. The magnification is equal to the radius of the larger pulley divided by the radius of the smaller pulley.

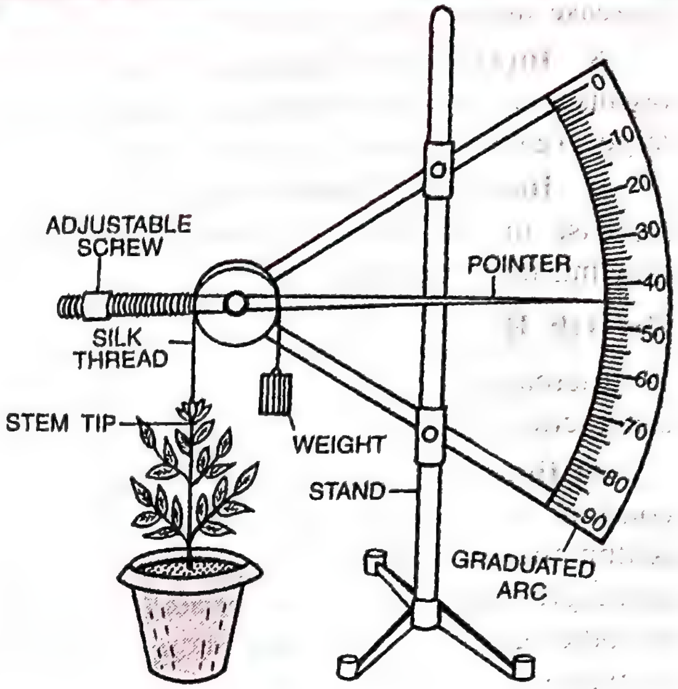


Fig. 15.6. Measurement of Growth by Arc Auxanometer.

Unspun silken thread is tied to the stem tip of a plant. The free end of the thread is attached to a small weight. The thread is now passed over the smaller pulley in the direction opposite to that of the revolving cylinder. Another thread is passed over the larger pulley. It bears small weights at both its free ends. This thread bears an horizontal pointer on the side of the revolving cylinder (Fig. 15.7). The pointer is in contact with the smoked paper which is wrapped or pasted over the revolving cylinder. The smoked paper is prepared by passing plain paper over burning camphor or oil lamp. Graph paper can also be used instead of smoked one. In that case the tip of the pointer is inked.

The clockwork of the revolving cylinder is started. As growth occurs, the two pulleys will move with the downward movement of the weight attached to the other end of the thread connected to the stem tip of plant. If no growth occurs, the pointer will mark only an horizontal line on the smoked paper. A stair case like line will show the diurnal pattern of growth.

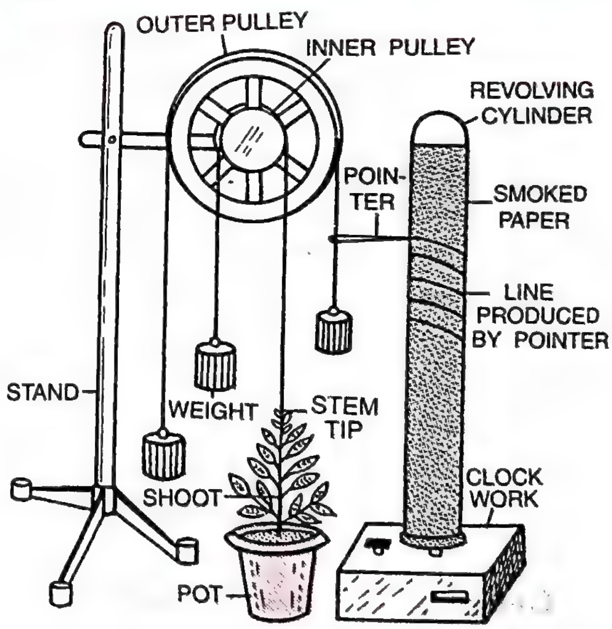


Fig. 15.7. Measurement of Growth by Automatic Auxanometer.

The automatic auxanometer is an improvement over the arc auxanometer. It can register total growth, rate of growth at specific time and overall pattern of growth.

5. **Increase in Cell Number.** In bacteria, yeast and many algae, the rate of growth is estimated by the increase in number of cells.

6. **Increase in Weight.** Both fresh and dry weights are used for measuring growth. Fresh weight is used for measuring growth in fruits, bulbs, corms, roots etc. Dry weight is used for actual measurement of growth. For this the organs are dried in an oven at 110°C for several hours.

7. **Increase in Volume.** It is used in case of fruits. The fruit is dipped in water. Increase in level of water will indicate the volume of fruit.

8. **Increase in Diameter.** The method is used in case of globular and cylindrical organs, *e.g.*, fruits, tree trunk. Vernier callipers for small organs and measuring tapes for large organs are used.

9. **Increase in Surface Area.** It is used for measuring growth in flat organs like leaves. Increase in surface area is measured by placing the leaf on a standard graph paper and drawing its outline at fixed intervals.

Growth Rates

Increase in growth per unit time is called growth rate. Growth rate may result in arithmetic or geometric growth.

Arithmetic Growth (Fig. 15.8). It is a type of growth in which the rate of growth is constant and increase in growth occurs in arithmetic progression— 2, 4, 6, 8, 10, 12. Arithmetic growth is found in root or shoot elongating at constant rate. Meristematic cells at the growing point divide in such a fashion that one daughter remains meristematic while the other grows and differentiates. The process continues. Mathematically arithmetic growth is expressed as

$$L_t = L_0 + rt$$

L_t = length after time t. L_0 = length at the beginning. r = growth rate. On plotting growth against time, a linear curve is obtained (Fig. 15.8 B)

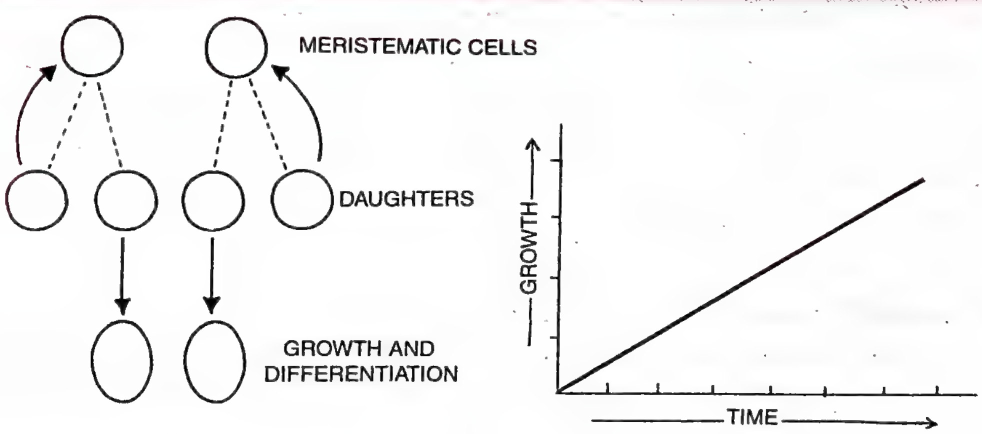


Fig. 15.8. Arithmetic growth. A, formation of new cells. B, growth curve.

Geometric Growth (Fig. 15.9). It is quite common in unicellular organisms when grown in nutrient rich medium. Here, every cell divides. The daughters grow and divide. The grand daughters repeat the process and so on. Number of cells is initially small so that initial growth is slow. Later on, there is rapid growth at exponential rate. It is called log or exponential growth.

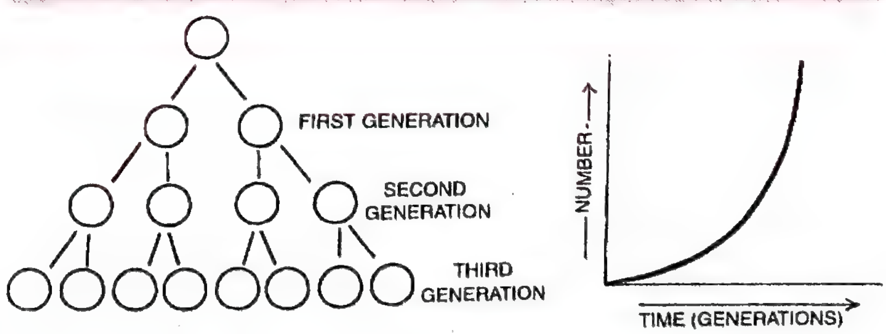


Fig. 15.9. Geometric growth. A, formation of new cells. B, J-shaped growth curve.

An embryo initially shows geometrical growth in cells but later it passes into arithmetic phase (Fig. 15.10).

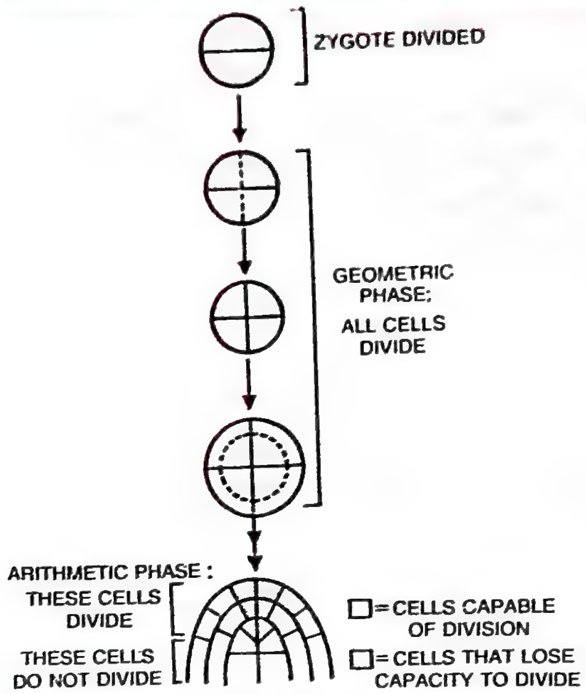


Fig. 15.10. Embryo showing geometric and arithmetic phases.

Differences between Arithmetic and Geometrical Growths

Arithmetic Growth	*Geometrical Growth*
1. Rate of growth is constant.	1. Rate of growth increases exponentially.
2. It can be sustained for long.	2. It cannot be sustained for long.
3. It gives a linear curve.	3. It gives a J-shaped curve.
4. It is found in stem and root growth.	4. It is found in initial multiplication of unicellular organisms and growth of very early embryo.

Sigmoid Growth Curve. Geometric growth cannot be sustained for long. Some cells die. Limited nutrient availability causes slowing down of growth. It leads to stationary phase. (There may be actually a decline). Plotting the growth against time will give a typical sigmoid or S-curve (Fig. 15.11).

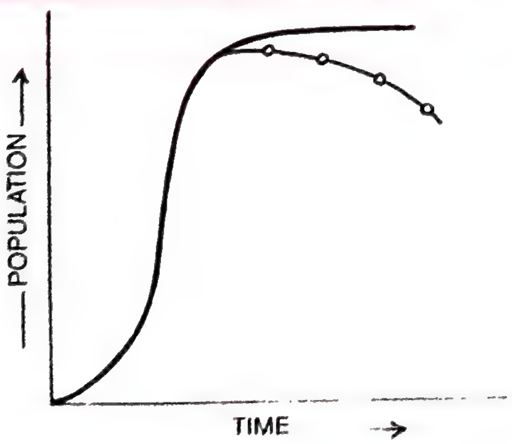


Fig. 15.11. Growth of a population of unicellular organisms.

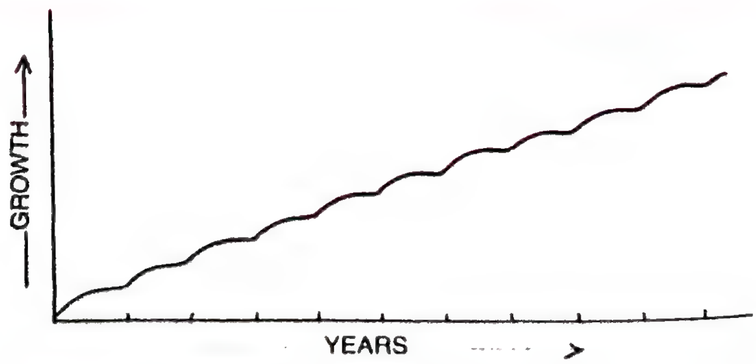


Fig. 15.12. Intermittant growth of a tree.

S-curve of growth is typical of most living organisms in their natural environment. It also occurs in cells, tissues and organs of plants. However, S-curves of individual cells, tissues, organs and the organisms may not be synchronous because one cell after differentiation may enter the stationary phase while a second one after being formed may be in lag phase. Similarly, some leaves of a branch growing exponentially may be just formed, others showing lag phase, log phase and mature phase. Some leaves may be in the process of abscission. Most plants also show seasonal growth. The S-shaped growth curve would exhibit small stationary phase at the end of each annual growth (Fig. 15.12).

Law of Compound Interest (Exponential Growth). Growth is dependent on three factors— initial size (W_0), rate of growth (r) and the time interval for which the rate of growth can be retained. It is just like depositing money in a bank. The money will grow at compound interest. Growth will depend upon the initial size (amount of money deposited), rate of growth (rate of interest) and the period for which it is sustained (period of time in the bank).

$$W_1 = W_0 e^{rt}$$

Here W_1 is the final size, W_0 is initial size, r is growth rate, t is time of growth while e is the base of natural logarithms (2.71828). The magnitude of r or rate of growth has been called **efficiency index** by Blackman (1919) as the organs and organisms with higher r value will out perform others with low r value.

Quantitative comparisons between growth of various systems can be made by measuring their absolute and relative growth rates.

Absolute Growth Rate. Absolute growth curve is the **actual growth curve** obtained by plotting growth against time. It is commonly S-shaped. **Absolute growth rate** is the total growth per unit time. A graph plotted for absolute growth rates for various times of grand period of growth appears **bell shaped**. The peak is formed when the growth rate is the fastest. The period of increasing growth is depicted by the first part of the curve while the period of decreasing growth rate is shown by the second part of the curve (Fig. 15.13).

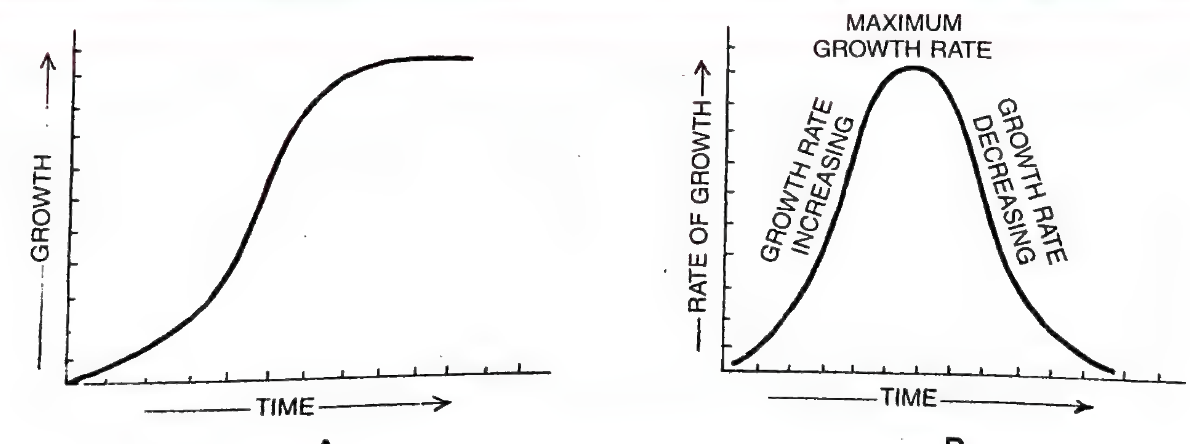


Fig. 15.13. A, absolute or actual growth curve. B, absolute growth rate curve.

Relative Growth Rate. It is growth per unit time per unit initial growth.

$$\frac{\text{Growth in Given Time Period}}{\text{Measurement at Start of Time Period}}$$

Suppose two leaves have grown by 5 cm^2 in one day. Initial size of leaf A was 10 cm^2 while that of leaf B was 15 cm^2. Though their absolute growth is the same, relative rate of

growth is faster in leaf A because of initial small size (Fig. 15.14). It decreases with time (Fig. 15.15).

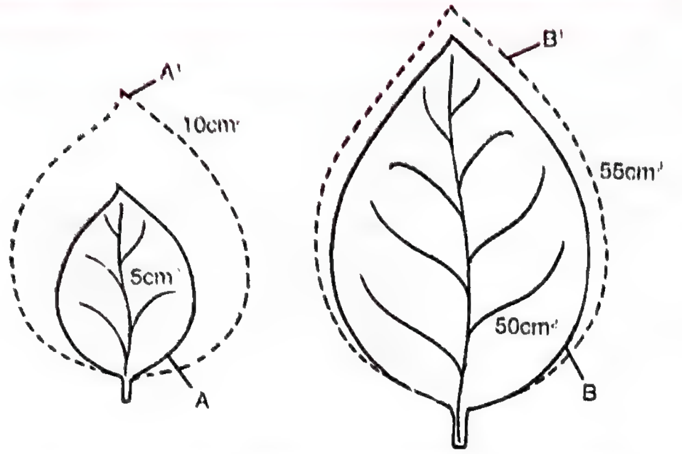


Fig. 15.14. Comparison of absolute and relative growth rates in two leaves showing 5cm² growth per day.

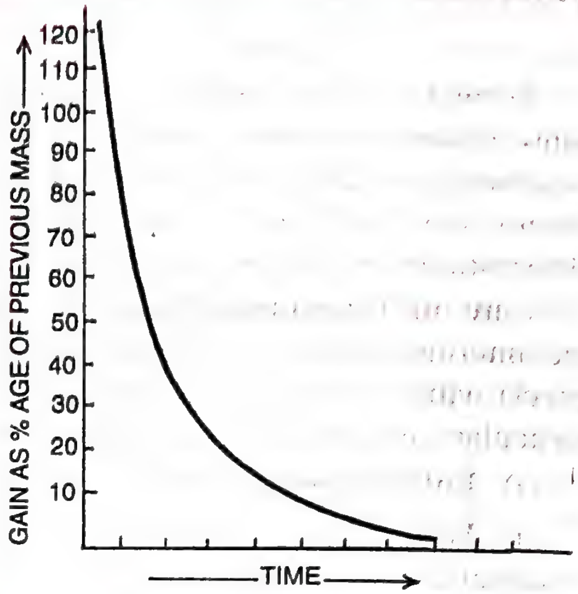


Fig. 15.15. Relative growth rate of a seedling.

Conditions for Growth

Growth involves synthesis of more protoplasm, cell division, cell enlargement and cell differentiation. It is, therefore, influenced by all those factors which influence biosynthetic machinery, availability of water, oxygen, optimum temperature, optimum light, minerals and absence of stress conditions.

1. **Nutrients.** They are raw materials for synthesis of protoplasm as well as source of energy. It is seen that rate of growth is proportional to size of bulb, tuber, rhizome, etc. It is called **law of mass growth**. Nutrients should be rich in nitrogenous components for increased synthesis of protoplasm and carbohydrates for energy and cell wall synthesis. All types of micronutrients (micro-essential elements) and macronutrients (macro-essential elements) must be available for proper growth.

2. **Water.** It is required for cell elongation, maintenance of turgidity of growing cells and providing medium for enzyme action. Even slight deficiency of water reduces growth. It may, however, promote differentiation. Water stress completely stops growth.

3. **Oxygen.** It is essential for aerobic respiration and hence availability of energy for biosynthetic activity.

4. **Light.** It is required for tissue differentiation, synthesis of photosynthetic pigments and photosynthesis. Its absence results in etiolation. Light also influences certain stages of growth. The phenomenon is called photoperiodism.

5. **Temperature.** A temperature of 28°–30°C is optimum for proper growth in most plants. Higher temperature above 45°C hinders growth due to excessive transpiration, denaturation of enzymes and coagulation of protoplasm. Lower temperature inactivates enzymes as well as increases density of protoplasm.

6. **Gravity.** Vector of gravity determines the direction of shoot and root growth. Direction of light also determines the orientation of leafy shoots.

7. **Other Factors.** Excess of salt, mineral deficiency and other stress factors have a detrimental effect on growth.

Differentiation, Dedifferentiation and Redifferentiation

Differentiation

Growth is invariably associated with **differentiation**. For example, when a seed germinates, it does not simply increase in size but forms a seedling. *Differentiation is a permanent localised qualitative change in size, biochemistry, structure and function of cells, tissues or organs, e.g.,* fibre, vessel, tracheid, sieve tube, mesophyll, leaf, etc. The exact trigger for differentiation is not known. All the cells of an individual have the same genetic information. They are influenced by similar external factors. Depending upon the location inside the plant and internal cellular mechanism, some genes are repressed (not allowed to express their effect) while others are allowed to show their effect. This causes the cells to behave in a particular fashion during growth and after maturation—

(i) Enlargement, lignocellulosic wall thickening and emptying in case of tracheids,

(ii) Widening, some enlargement, wall thickening, emptying and loss of end wall in case of vessel elements,

(iii) Loss of nucleus, vacuolisation and perforation of end wall in sieve tube members,

(iv) Development of abundant chloroplasts in mesophyll cells,

(v) Deposition of suberin in cell walls, tannins in protoplasts and then death of cork cells,

(vi) Deposition of silica in epidermal cells of grasses,

(vii) Differential wall thickening, small vacuoles, formation of a few chloroplasts and small size in guard cells,

(viii) Free nuclear division, a central canal and secretion of latex in laticifers,

(ix) Secretion of mucilage in root cap,

(x) Elongation, thickening and emptying of sclerenchyma fibres,

(xi) Development of uneven pectocellulosic thickening in collenchyma,

(xii) Cutinisation of trichomes for preventing transpiration and formation of stationary air layer, and

(xiii) Development of schizogenous interspaces to form aerenchyma in aquatic plants.

Not only the plants are open-ended, their differentiation is also open. The same apical meristem cells give rise to different types of cells, *e.g.*, xylem, phloem, parenchyma, sclerenchyma fibres, collenchyma, etc. The reason for the formation of different types of cells and tissues from the same type of meristematic cells is **commitment** or **determination**. It is generally due to location and reception of particular signals. For example, cells distal to root apical meristem form root cap, while on the periphery they form epiblema followed by cortex, endodermis, pericycle, vascular tissues, etc.

Table 15.1. Differentiation in some cell types

Cell/Tissue Type	*Structural Characteristic*	*Functions Performed*
1. Palisade Parenchyma	Abundant chloroplasts.	Photosynthesis.
2. Tracheid	Lignocellulosic wall thickening and emptying.	Conduction of sap.
3. Guard Cells	Reniform, shape and differential wall thickening.	Creation and regulation of stomatal pores.
4. Root Cap	Secretion of mucilage and covering of root apical meristem.	Protection of RAM and growth in soil.

5. Fibre	Elongation, wall thickening and emptying.	Mechanical strength.
6. Collenchyma	Uneven pectocellulosic thickening.	Strength and flexibility.
7. Trichome	Cutinisation and surface outgrowth.	Reduction in transpiration and formation of stationary air layer.

Dedifferentiation and Redifferentiation

The process of despecialisation of differentiated cells so that they become undifferentiated and able to divide is known as **dedifferentiation**. It involves activation of certain genes which not only reverse differentiation but also stimulate cell division. Cork cambium, wound cambium and interfascicular vascular cambium are always produced through dedifferentiation. Cell culture experiments are based on dedifferentiation of cells and formation of mass of undifferentiated cells called callus. Normally cells produced by dedifferentiated cells mature and form redifferentiated cells, *e.g.*, secondary xylem elements, secondary phloem elements, cork cells.

Development

Development is the sequence of events that occur in the life history of a cell, organ or organism which includes seed germination, growth, differentiation, maturation, flowering, seed formation and senescence. The term development is also applied to changes in phases of life, *e.g.*, vegetative to flowering leaf initiation to leaf expansion. Development occurs even at the subcellular level, *e.g.*, appearance of chloroplasts in cells exposed to light. The last phase of development is senescence. Senescence or old age leads to death.

Sequence of events occurring during development of cells of higher plants are as follows:

$$
\begin{array}{c}
\text{Meristematic cell} \xleftarrow{\text{Cell Division}} \text{Meristematic cell} \xrightarrow{\text{Cell Division}} \text{New cell} \\
\text{Meristematic cell} \xrightarrow[\text{Growth}]{\text{Plasmatic}} \text{New cell} \xrightarrow{\text{Expansion}} \text{Enlargement} \xrightarrow{\text{Differentiation}} \text{Maturation} \rightarrow \text{Mature Cell} \\
\text{Death} \xleftarrow{\text{Senescence}} \text{Mature Cell}
\end{array}
$$

Different structures develop in different phases of growth as well as in response to environment. There are three development stages — juvenile, adult vegetative and adult reproductive stages. Vegetative reproductive from juvenile stage produces juvenile plants while the same from adult stage give rise to adult plants. The ability to change under the influence of internal or external stimuli is called **plasticity**. The intrinsic plasticity is found in juvenile stage of many plants, *e.g.*, Cotton, Coriander, Larkspur, Ivy. Environmental plasticity is best seen in emergent hydrophytes like Buttercup (*Ranunculus flabellaris*). In both cases plants show heterophylly and a number of other morphological features. **Heterophylly** is the occurrence of different types of leaves on the same plant habitually in different growth phases or under different environmental conditions. In case of environmental plasticity shown by aquatic Butter cup *Ranunculus flagellaris*, the submerged leaves are highly dissected while the emerged leaves are broad and lobed. In Larkspur, the juvenile leaves are broadly lobed while the mature leaves become pinnately divided with lobes becoming linear in the region of flowers.

In *Hedera helix* (Ivy) the juvenile plant is root climber having alternate palmately lobed

leaves while the adult plant has bushy habit with opposite entire leaves. It bears flowers and fruits. The fruits contain seeds for formation of new plants. Annuals, biennials and perennial monocarpic plants become senescent after the formation of fruits and hence die. Perennial

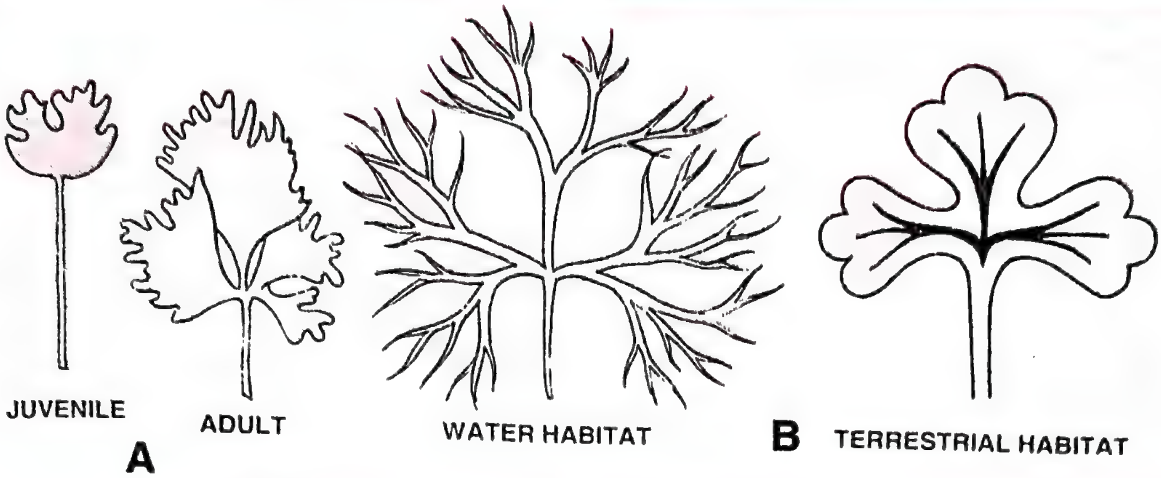


Fig. 15.16. Heterophylly. (A) Larkspur, (B) Buttercup.

polycarpic plants continue to grow indefinitely and bear flowers and fruits annually after attaining maturation. However, growth of a perennial plant is not uniform throughout the year. In a calender year, it shows periods of active vegetative growth, flowering, fruiting, senescence and dormancy. The different **aspects** or appearances of plants in different seasons of a year is called **phenology**.

Development includes growth and differentiation. It is under control of both intrinsic and extrinsic factors. Intrinsic factors include genetic factors and growth regulators. Extrinsic factors are light, temperature, water, oxygen and nutrition.

PLANT GROWTH REGULATORS (PGR)

Plant growth regulators are small, simple molecules of diverse chemical composition, which in low concentration regulate growth, differentiation and development by promoting or inhibiting the same. One type of plant growth regulators are **plant hormones** or **phytohormones**. Technically *a plant hormone is a chemical substance other than nutrient produced naturally in plants, which may be translocated to another region, for regulating one or more physiological reactions when present in low concentration*. Five types of phytohormones are known. They are indole compounds (*e.g.*, Indole acetic acid or IAA), adenine derivatives (*e.g.*, furfuryl, aminopurine, kinetin, cytokinins), derivatives of carotenoids and fatty acids (abscisic acid, ABA), terpenes (gibberellins, *e.g.*, GA_3 or gibberellic acid) and gases (ethylene, C_2H_4). Other related growth regulators are salicylic acid, jasmonic acid and brassinosteroids. Some vitamins also regulate plant growth.

PGRs are broadly divided into two groups, plant growth promoters and plant growth inhibitors. Plant growth promotors perform growth promoting activities like cell division, cell enlargement, pattern formation, tropic growth, flowering, fruiting and seed formation. They are three in number *viz.*, auxins, gibberellins and cytokinins. Plant growth inhibitors normally induce dormancy and abscission. They have, however, an important function in inducing plant responses to wounding, biotic and abiotic stresses. Abscisic acid is known plant growth inhibitor. Ethylene is largely plant growth inhibitor but is also involved in some growth promotion activities.

1. PGRs are involved in a variety of growth, differentiation and developmental responses.

2. The response to a PGR may differ from one plant organ to another. Auxin promotes growth of apical bud but inhibits growth of axillary buds. The concentration of auxin which promotes stem growth is inhibitory to root growth.

3. Similar responses may be shown by different PGRs. Auxins and gibberellins promote cell growth while the three growth promotors (auxins, gibberellins, cytokinins) are involved in cell division.

4. Plant growth regulators are effective at very low concentration, usually in the range of 10^{-6} M.

5. The site of production and site of action (target cells) of plant growth regulators may be different (as in case of animal hormones) or the same (unlike animal hormones).

6. There is no specialised tissue or gland for producing a plant growth regulator. Instead it can be synthesized at many places by different tissues within the plant body.

AUXINS (Gk. *auxein*– to grow)

They are weakly acidic growth hormones having an unsaturated ring structure and capable of promoting cell elongation, especially of shoots (more pronounced in decapitated shoots and shoot segments) at a concentration of less than 100 ppm which is inhibitory to the roots. Among the growth regulators auxins were the first to be discovered. However, the discovery of auxin and other types of PGRs has been accidental.

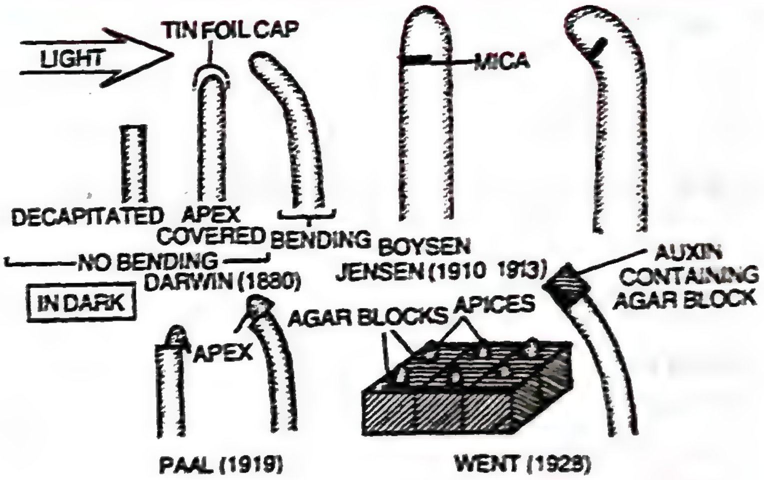
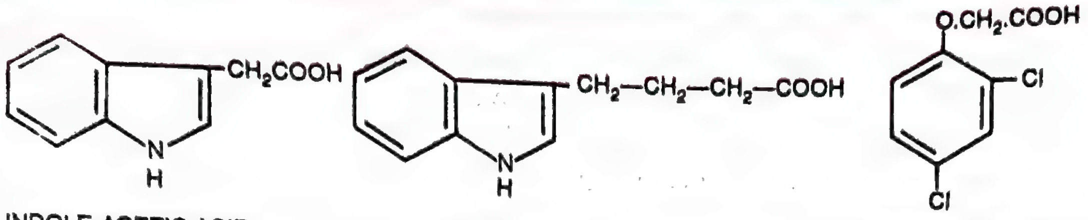


Fig. 15.17. Summary of early work on auxin.

History (Fig. 15.17). Charles Darwin and his son Francis Darwin (1880) found that the sensation of unilateral illumination was picked up by the coleoptile tip of Canary Grass (*Phalaris canarensis*). A decapitated coleoptile did not receive the sensation. Coleoptile tip covered by an opaque tin foil cap also could not perceive the stimulus of light. The sensation picked up by the coleoptile tip is transmitted to the subapical part which it bends in relation to the direction of light. Boysen–Jensen (1910–1913) showed that the sensation of phototropism picked up by coleoptile tip could be transmitted to subapical region through a block of gelatine but not through a mica plate. Paal (1919) replaced the previously exposed excised tip eccentrically over the stump of coleoptile. He observed greater growth on that side even in dark. Went (1928) collected the growth stimulating substance in agar jelly. He discovered that the hormone travelled basipetally, *i.e.*, from tip or apex towards the base. Agar block containing the chemical caused bending of a decapitated coleoptile according to its concentration. The growth promoting substance was named by him as **auxin** (Gk. *auxein*– to grow). Kogl and Haagen-Smith (1931) isolated three chemicals from human urine. They were named as auxin *a*, auxin *b*, and heteroauxin. Kogl *et al* (1934) found that heteroauxin is the real plant auxin and is chemically indole 3-acetic acid or IAA. It is also present in urine of human beings suffering from pellagra, a disease caused by deficiency of niacin (= nicotinic acid).

Indole 3-Acetic Acid (IAA, Fig. 15.18) is the universal natural auxin. It was discovered by Kogl *et al* (1934). Related chemicals are indole 3-acetaldehyde, indole 3-acetonitrile, indole 3-butyric acid (IBA), phenyl acetic acid and 4-chloro indole acetic acid. All of them have auxin like activity. Auxin is synthesised in shoot apices, leaf primordia and developing seeds from amino acid tryptophan. A tryptophan independent pathway has also been discovered recently. Auxin passes from shoot tip to the region of elongation. Auxin movement is polar. It is basipetal in stem but acropetal in the root. Auxin helps in the elongation of both roots and shoots. However, the optimum for the two is quite different (Fig. 15.19). It is 10 ppm for stem and 0.0001 ppm for the root. In higher concentration auxin inhibits growth.



INDOLE-ACETIC ACID (IAA) INDOLE-BUTYRIC ACID (IBA) 2-4 DICHLOROPHENOXY ACETIC ACID (2-4D)

Fig. 15.18. Some common auxins.

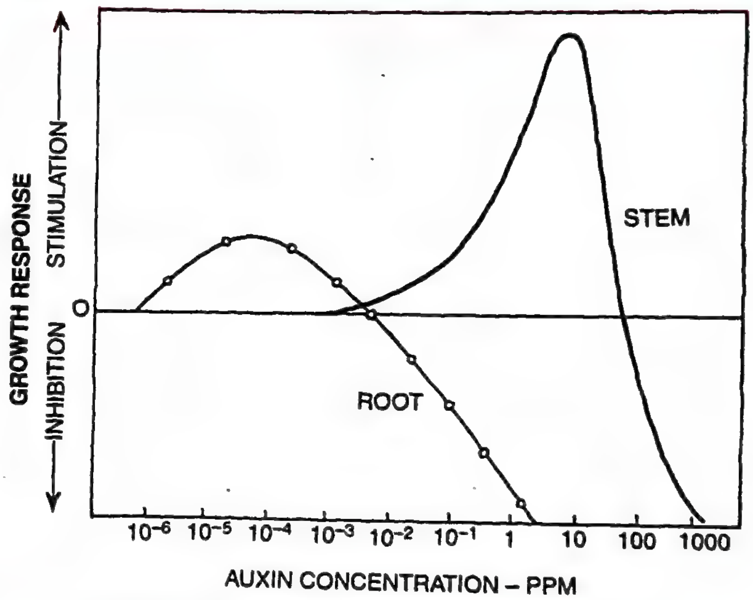


Fig. 15.19. Effect of auxin concentration on growth of root and stem.

The raw material which is used in synthesis of auxin is called **auxin precursor**. It is tryptophan for IAA. Certain compounds inhibit action of auxin. They are called antiauxins, *e.g.*, *p*-chlorophenoxy isobutyric acid (PCIB). TIBA (2, 3, 5 triiodobenzoic acid also acts as antiauxin by blocking the transport of auxin. Active form of auxin is **free auxin** or auxin which can be extracted easily. Auxin which cannot be extracted easily except with the help of organic solvents is called **bound auxin,** *e.g.*, IAA–aspartic acid, IBA–alanine, IAA–myoinositol, IAA–glucan, IAA–glycoprotein. Bound auxin is believed to be hormonally inactive (Hangarter and Good, 1981), being meant for storage and protection against degradation.

Synthetic Auxins. Many synthetic auxins are also being manufactured. The important ones are 2 : 4 D (2 : 4-dichlorophenoxy acetic acid), 2 : 4 : 5-T (2 : 4 : 5-trichlorophenoxy acetic acid), IBA (indole 3-butyric acid), NAA (naphthalene acetic acid). MCPA (2-methyl 4-chlorophenoxyacetic acid), Dicamba (2-methoxy 3-, 6-dichlorobenzoic acid). **IBA is both natural and synthetic.** Synthetic auxins move in all directions inside plants.

Bioassay

It is testing of a biological activity like growth response of a substance by employing a

living material like plant or plant part. Auxin bioassay is quantitative test as it measures concentration of auxin to produce the effect and the amount of effect.

1. **Avena Curvature Test** (Fig. 15.20). The test is based upon experiments of Went (1928). 10° curvature is produced by auxin concentration of 150 μg/litre at 25°C and 90% relative humidity. The test can measure auxin upto 300 μg/litre. Auxin from a shoot tip or any other plant organ is allowed to diffuse in a standard size agar block (generally 2 × 2 × 1 mm). Auxin can also be dissolved directly in agar. 15–30 mm long oat coleoptile grown in dark is held vertically over water. 1 mm tip of coleoptile is removed without injuring the primary leaf. After 3 hours a second decapitation is carried out for a distance of 4 mm. Primary leaf is now pulled loose and agar block supported against it at the tip of decapitated coleoptile. After 90–110 minutes, the coleoptile is found to have bent. The curvature is measured. It can also be photographed and the curvature known from shadow graph.

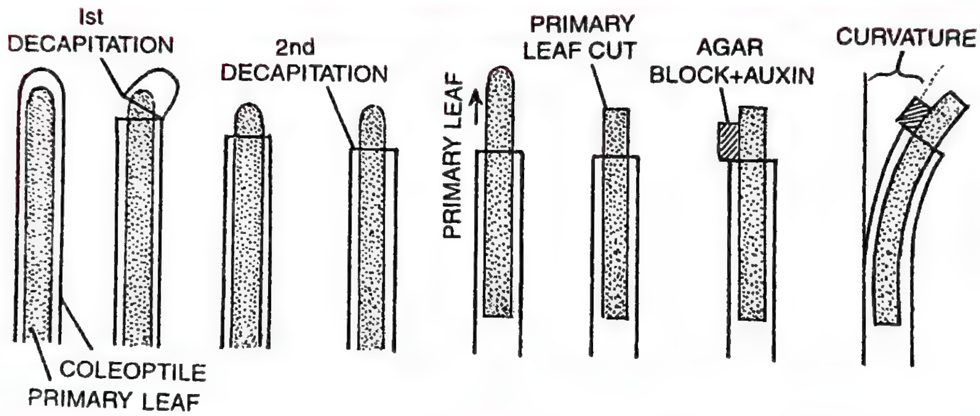


Fig. 15.20. Method of Avena Curvature Test.

2. **Root Growth Inhibition** (Cress Root Inhibition Test, Fig. 15.21) Sterilised seeds of Cress are allowed to germinate on moist filter paper. As the roots reach a length of 1 cm or so, root lengths are measured. 50% of the seedlings are placed in a test solution while the remaining are allowed to grow over moist paper. Lengths of the roots are measured after 48 hours. It is seen that the seedlings placed in test solution show very little root growth while root growth is normal in control seedlings.

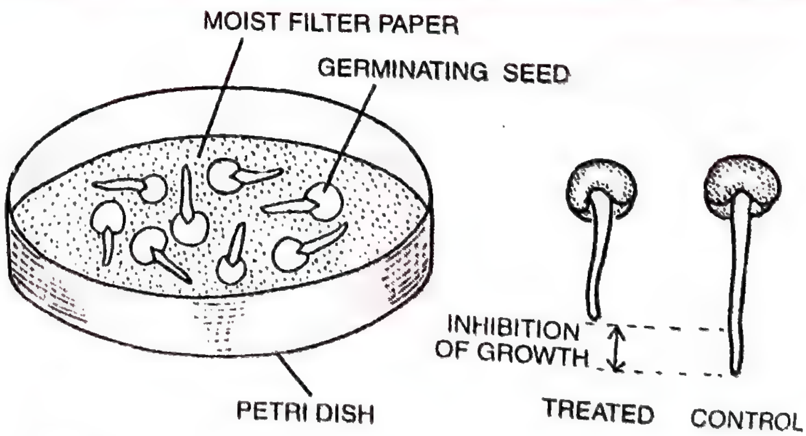


Fig. 15.21. Root growth inhibition bioassay of auxin.

Auxin Functions

1. **Respiration**. Auxins stimulate respiration most probably by increasing availability of respiratory substrate.

2. **Metabolism**. Application of auxin has been found to enhance metabolism due to mobilisation of plant resources.

3. **Solutes**. Auxins increase storage of solutes inside the cells.

4. **Cell Enlargement** (Fig. 15.22). It is the most fundamental activity of auxins. Cell enlargement is caused by solubilisation of carbohydrates, loosening of wall microfibrils, synthesis of more wall materials, increased membrane permeability and respiration.

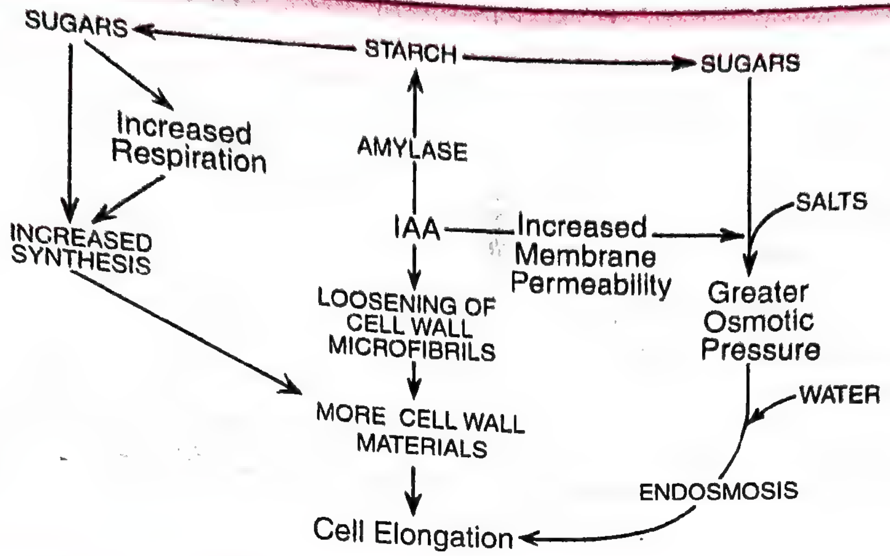


Fig. 15.22. Action of IAA in cell elongation.

5. **Cambial Activity**. Degree of cambial activity is directly proportional to auxin concentration (Avery *et al*, 1947). Auxin also controls xylem differentiation.

6. **Cell Division**. Auxin is known to promote division in the cells of vascular cambium.

7. **Tissue Culture**. In tissue culture, the development of callus or mass of undifferentiated cells is promoted by auxin. Differentiation of callus occurs in the presence of both auxin and cytokinin.

8. **Root Formation**. Auxin promotes root initiation at concentration which is inhibitory for growth of intact root.

9. **Apical Dominance** (Fig. 15.23). Apical dominance is the phenomenon by which presence of apical bud does not allow the nearby lateral buds to grow. When the apical bud

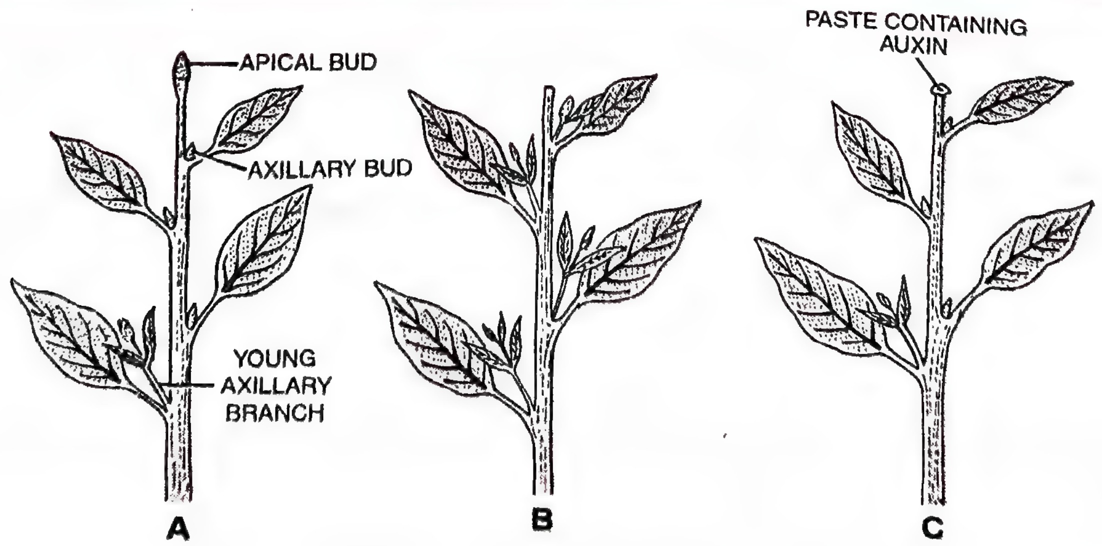


Fig. 15.23. Apical dominance and auxin. A, apical bud intact. B, removal of apical bud and loss of dominance. C, auxin applied over cut end inhibits lateral bud growths as in apical dominance.

is removed, the lateral buds sprout. This produces dense bushy growth. The phenomenon is widely used in tea plucking and hedge making. Apical bud inhibits the growth of lateral buds by releasing auxins. It is confirmed by painting the cut end of decapitated shoot by a paste of auxin. The lateral buds remain inhibited, as if the apical bud is present.

10. **Inhibition of Abscission.** Auxin delays abscission of young leaves and fruits. Its effect is through nonformation of abscission zone below a leaf or fruit. Abscission zone cuts off nutrients and water supply. However, auxin promotes the abscission of mature or older leaves and fruits.

11. **Tropic Movements.** Differential distribution of indole 3-acetic acid produces tropical plant responses like phototropism and geotropism.

12. **Sex.** Auxins have a feminising effect on some plants.

13. **Seedless Fruits.** The carpels producing seedless or parthenocarpic fruits have a higher internal production of auxin that supports the development of fruits, *e.g.,* Banana.

14. **Ethylene.** Higher concentration of IAA induces synthesis of ethylene.

15. **Membrane Potential.** It produces a negative potential on the cell membrane.

Uses of Auxins

1. **Rooting.** Auxins stimulate root formation on the stem cutting, *e.g.,* IBA, IBA-alanine, NAA (rootone).

2. **Parthenocarpy.** Application of auxins (*e.g.,* IAA, IBA) and conjugate auxins (*e.g.,* IBA-alanine) to unpollinated pistils make them develop into seedles fruits or parthenocarps which carry a better market price than the normal fruits having seeds, *e.g.,* Tomato.

3. **Weedicides** (= Herbicides). They are chemicals which kill weeds growing in the fields. Application of 2 : 4-D and 2 : 4 : 5-T removes broad leaved weeds in cereal crops and lawns because they do not affect mature monocotyledons while Dalapon (2-2 dichloropropionic acid) kills grasses in broad leaved crops. Weedicides should be used very carefully and only occasionally as they have wide spectrum and long lasting action. Thus weedicides or defoliants used in Vietnam have exterminated the wild relatives of *Citrus*.

4. **Flowering.** NAA and 2,4-D are often employed for inducing flowering in Litchi and Pineapple.

5. **Storage.** Methyl ester of NAA prevents the sprouting of Potato tubers kept in storage.

6. **Pre-Harvest Fruit Drop.** In low concentration 2,4-D is useful in preventing pre-harvest fruit drop of Orange and Apple. NAA is similarly useful for checking fruit drop of Tomato.

7. **Vegetable Crops.** Chlorophenoxy propionic acid enhances the quality of vegetable crops by preventing flower formation.

8. **Fruits.** Auxins enhance sweetening of fruits, *e.g.,* IBA.

9. **Prevention of Lodging.** Naphthalene acetamide (NAAM) prevents lodging or falling of crop plants during windy season.

10. **Dwarf Shoots.** In Apple, flowers and fruits are formed on dwarf shoots. Application of naphthalene acetic acid increases the number of dwarf shoots as well as the number of fruits.

GIBBERELLINS

Gibberellins are weakly acidic growth hormones having gibbane ring structure which cause cell elongation of intact plants in general and increased internodal length of genetically dwarfed plants (e.g., Pea, Corn), *in particular.*

History. The effect of gibberellins had been known in Japan since early 1800 where certain rice plants were found to suffer from **bakane** or **bakanae** (foolish seedling) disease. Such rice plants were thin, pale green, spindle shaped, longer by 50% than the healthy plants, and were sterile. The disease was found by Hori (1918) and Kurosawa (1926) to be caused by a fungus, *Gibberella fujikori*. The fungus is the perfect stage of *Fusarium moniliforme*. Kurosawa also found that the sterile filtrate of the fungus also caused appearance of disease symptoms in uninfected rice seedlings. The active substance was separated and named gibberellin by Yabuta (1935). Yabuta (1938) also prepared crystalline form of gibberellin (it actually consisted of six gibberellins). Japanese work came to light only after world war II. Gibberellic acid or GA_3 was isolated in pure form by Brian *et al* in 1955. Cross *et al* (1961) worked out the structure of gibberellic acid, GA_3 (Fig. 15.24). It is chemically $C_{19}H_{22}O_6$. GA_3 is one of the most intensively studied gibberellin. A mixture of GA_4 and GA_7 is used commercially. Until now 125 different gibberellins have been identified. Many of them occur naturally in plants and fungi. *Gibberella fujikori* has as many as 15 gibberellins. A single plant also possesses a number of gibberellins. This is in contrast to auxin, where a single natural hormone occurs. Gibberellins are synthesised in the apical shoot buds (young leaves), root tips and developing seeds. The precursors for their synthesis is mevalonic acid (derived from acetyl coenzyme A). Gibberellin transport occurs through simple diffusion as well as through conducting channels.

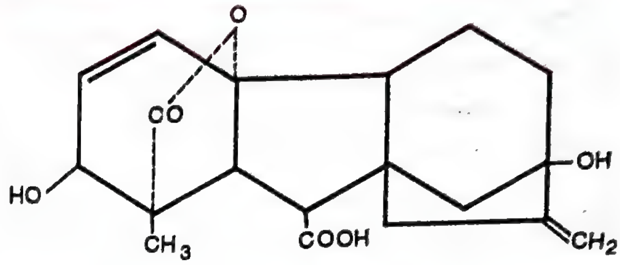


Fig. 15.24. Gibberellic acid (GA_3).

Bioassay

1. **Dwarf Pea.** Seeds of dwarf pea are allowed to germinate till the formation of coleoptile. GA solution is applied to some seedlings. Others are kept as control. After 5 days, epicotyl length is measured. GA stimulates epicotyl growth with a concentration as low as 1 nanogram.

2. **Barley Endosperm.** Endosperms are detached from embryos, sterilised and allowed to remain in 1 ml of test solution for 1–2 days. There is a build up of reducing sugars. The content of reducing sugar is proportional to gibberellin concentration. Reducing sugars are not formed in control experiment where endosperms are kept in plain water.

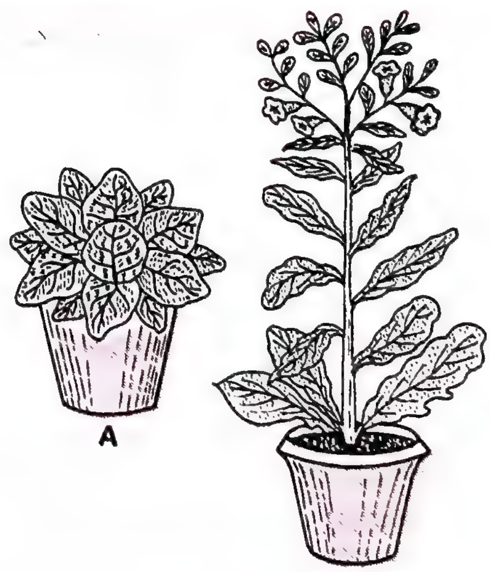


Fig. 15.25. Effect of gibberellin on cabbage. A, untreated. B, treated.

Gibberellin Functions

1. **Stem and Leaf Growth.** Gibberellins help in cell growth of stem, leaves and other aerial parts.

Therefore, they increase the size of stem, leaves, flowers and fruits. Gibberellins, however, do not seem to play any such part in case of roots.

2. **Dwarf Shoots.** Besides general increase in stem length, gibberellins specifically induce internodal growth in some genetically dwarf varieties of plants like Pea and Maize. It appears that dwarfness of such varieties is due to internal deficiency of gibberellins.

3. **Bolting.** Gibberellins induce subapical meristem to develop faster. This causes elongation of reduced stem or **bolting** in case of **rosette plants** (*e.g.*, Henbane, Cabbage, Fig. 15.25) and **root crops** (*e.g.*, Radish). A weekly doze of 0.1 mg gibberellic acid made cabbage plants to grow taller than 3.5 m. Normally bolting occurs at the onset of reproductive phase. It is favoured in nature by either cold nights or long days.

4. **Dormancy.** Gibberellins overcome the natural dormancy of buds, tubers, seeds, etc. and allow them to grow. In this function they are antagonistic to abscisic acid (ABA).

5. **Seed Germination.** During seed germination, especially of cereals, gibberellins stimulate the production of some messenger RNAs and then hydrolytic enzymes like amylases, lipases, ribonucleases and proteases. The enzymes solubilise the reserve food of the seed. The same is transferred to embryo axis for its growth.

6. **Fruit Development.** Alongwith auxin, gibberellins control fruit growth and development. They can induce parthenocarpy or development of seedless fruits from unfertilized pistils, especially in case of pomes (*e.g.*, Apple, Pear).

7. **Flowering.** They promote flowering in long day plants during non-inductive periods.

8. **Vernalization.** Vernalization or low temperature requirement of some plants can be replaced by gibberellins.

9. **Sex Expression.** Gibberellins promote the formation of male flowers on genetically female plants of *Cannabis*. They can also replace female flowers with male flowers on monoecious plants of cucurbits.

10. **Curvatures.** In Sunflower, phototropic and geotropic responses of shoot tips are due to redistribution of gibberellins (Phillips, 1972).

Gibberellin Uses

1. **Fruit Growth.** Application of gibberellins increases the number and size of several fruits, *e.g.*, Grape, Tomato. The hormone creates more room by increasing the size of stalks so that fruits can grow in size. Size and shape of Apple fruits is enhanced by application of GA_4 and GA_7 mixture.

2. **Parthenocarpy.** Seedless pomaceous fruits can be produced by application of gibberellins to unpollinated flowers.

3. **Malt.** Gibberellins (*e.g.*, GA_3) increase the yield of malt from barley grains.

4. **Overcoming Dormancy.** Gibberellins can be employed for breaking seed and bud dormancy. They induce germination of positively photoblastic seeds of Tobacco and Lettuce in complete darkness.

5. **Delayed Ripening.** GA_7 delays senescence so that fruit can be left on the tree for longer period. It extends period of marketing. Ripening of *Citrus* fruits can be delayed with the help of gibberellins. This is useful in storing the fruits.

6. **Flowering.** Gibberellins can be used in inducing offseason flowering in many long day plants as well as plants requiring vernalisation.

7. **Sugarcane.** Spraying of sugarcane crop with gibberellins increases length of stem and yield of sugarcane to as much as 20 tonnes/acre.

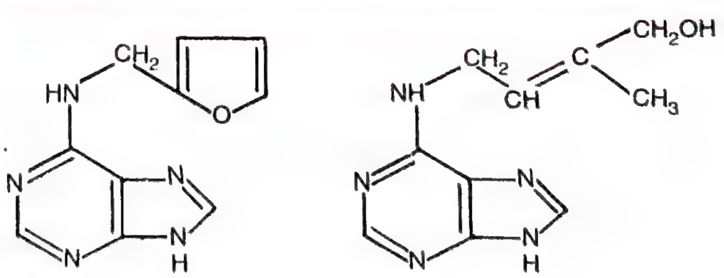
8. **Early Maturity**. Juvenile conifers sprayed with mixture of GA_4 and GA_7 reach maturity quite early resulting in early seed production.

Differences Between Auxin and Gibberellin

Auxin	*Gibberellin*
1. Auxin has a single or double unsaturated ring structure and a side chain.	1. Gibberellin possesses a gibbane ring structure.
2. Auxin transport is basipetal.	2. Gibberellin transport is both basipetal and acropetal.
3. It promotes growth of shoot segments.	3. It promotes growth of intact stem as well as leaves.
4. Auxin brings about apical dominance.	4. Gibberellin has no role in apical dominance.
5. Genetically dwarf shoots do not elongate.	5. Genetically dwarf shoots often elongate after gibberellin treatment.
6. Normal concentration of auxin inhibits root growth.	6. Gibberellin has no such effect.
7. It does not cause bolting.	7. It causes bolting in rosette plants.
8. It is essential for callus growth.	8. It has no role in callus growth.
9. Auxin does not help in breaking seed and bud dormancy.	9. Gibberellin is required in germination of most seeds and breaking of bud dormancy.
10. Natural auxin has no effect in induction of flowering in long day plants and plants requiring vernalisation.	10. Gibberellin promotes flowering in long day plants and plants requiring vernalisation.
11. It promotes root formation.	11. Gibberellin does not promote rooting.
12. Auxin does not mobilise food reserve during seed germination.	12. Gibberellin mobilises food reserve during seed germination by inducing formation of hydrolytic enzymes.
13. Auxin has feminising effect in some plants.	13. Gibberellin has masculinising effect in some plants.

CYTOKININS (Letham, 1963)

They are plant growth hormones which are basic in nature, either aminopurine or phenyl urea derivatives, that promote **cytokinesis** (= cell division) either alone or in conjunction with auxin. Skoog and co-workers found that callus from internodal segments of Tobacco proliferate only when in addition to auxin, the nutrient medium is provided with extract of yeast, vascular tissues, coconut milk or DNA. They were analysed to find out the growth promoting chemical. The first cytokinin was discovered from degraded autoclaved Herring sperm DNA by Miller *et al*, 1955. It is called **kinetin** (6-furfuryl amino-purine). Kinetin does not occur naturally. It is a synthetic hormone. The first natural cytokinin was obtained from unripe maize grains and coconut milk by Letham *et al* (1964). It is known as **zeatin** (6-hydroxy 3-methyl trans 2-butenyl amino-purine). It also occurs in coconut milk. Upto now 18 types of cytokinins have been discovered. Some of them are constituents of transfer RNAs. Roots



KINETIN
(6-FURFURYL AMINO PURINE)

ZEATIN
(6 - (4-HYDROXY 3-METHYL-TRANS-2-BUTENYL) AMINO PURINE)

Fig. 15.26. Two common cytokinins.

seem to be the major source of cytokinin synthesis. From roots the cytokinins pass upwardly through xylem. Some cytokinin synthesis also takes place in other areas where cell divisions are occurring like endosperm region of seeds, growing embryos and developing seeds, young fruits, developing shoot buds, etc. Coconut milk is a rich source of cytokinin.

Bioassay

1. **Tobacco Pith Culture.** Out of two tobacco pith cultures, one is supplied with cytokinin while the other is not. Increase in fresh weight of the tissue over the control is a measure of stimulation of cell divisions and hence cytokinin activity. The test can measure cytokinin concentration between 0.001–10 mg/litre. It takes 3–5 weeks.

2. **Retardation of Leaf Senescence.** It is a rapid bioassay technique. Leaf discs are taken in two lots. In one lot cytokinin is provided. After 48–72 hours, the leaf discs are compared for chlorophyll content. Cytokinin retards the process of chlorophyll degradation. The test is sensitive in concentration of 1 μg/litre.

3. **Excised Radish Cotyledon Expansion.** The test was developed by Letham. Excised Radish cotyledons are measured and placed in test solution as well as ordinary water (as control). Enlargement of cotyledons is an indication of cytokinin activity.

Cytokinin Functions

1. **Cell Division.** Cytokinins are essential for cytokinesis though chromosome doubling can occur in their absence. In the presence of auxin, cytokinins bring about division even in permanent cells. Cell division in callus (unorganised, undifferentiated irregular mass of dividing cells in tissue culture) is found to require both the hormones.

2. **Cell Elongation**. Like auxin and gibberellins, cytokinins also cause cell elongation.

3. **Morphogenesis**. Both auxin and cytokinins are essential for morphogenesis or differentiation of tissues and organs. Buds develop when cytokinins are in excess while roots are formed when their ratios are reversed (Skoog and Miller, 1957).

4. **Differentiation**. Cytokinins induce formation of new leaves, chloroplasts in leaves, lateral shoot formation and adventitious shoot formation. They also bring about lignification and differentiation of interfascicular cambium.

5. **Senescence** (Richmond-Lang Effect). Cytokinins delay the senescence of leaves and other organs by mobilisation of nutrients.

6. **Apical Dominance**. Presence of cytokinin in an area causes preferential movement of nutrients towards it. When applied to lateral buds, they help in their growth despite the presence of apical bud. They thus act antagonistically to auxin which promotes apical dominance.

7. **Seed Dormancy**. Like gibberellins, they overcome seed dormancy of various types, including red light requirement of Lettuce and Tobacco seeds.

8. **Resistance**. Cytokinins increase resistance to high or low temperature and disease.

9. **Phloem Transport**. They help in phloem transport.

10. **Accumulation of Salts**. Cytokinins induce accumulation of salts inside the cells.

11. **Flowering**. Cytokinins can replace photoperiodic requirement of flowering in certain cases.

12. **Sex Expression**. Like auxins and ethylene, cytokinins promote femaleness in flowers.

13. **Parthenocarpy**. Crane (1965) has reported induction of parthenocarpy through cytokinin treatment.

Cytokinin Uses

1. **Tissue Culture**. Cytokinins are essential for tissue culture because besides cell division they are also involved in morphogenesis. Instead of direct addition of cytokinins, the latter may be provided to tissue culture through the addition of coconut milk or yeast extract.

2. **Shelf Life**. Application of cytokinins to marketed vegetables can keep them fresh for several days. Shelf life of cut shoots and flowers is prolonged by employing the hormones.

3. **Resistance**. Cytokinin application is helpful to plants in developing resistance to pathogens and extremes of temperature.

4. **Overcoming Senescence**. Cytokinins delay senescence of intact plant parts.

ETHYLENE ($H_2C = CH_2$)

It is a gaseous hormone which stimulates transverse or isodiametric growth but retards the longitudinal one. Businessmen dealing with storing and shipping of fruits had known quite early that a rotten or ripe fruit could trigger early ripening of other fruits present nearby. Cousins (1910) found that ripe oranges produced a volatile substance that hastened ripening of unriped bananas nearby. With the help of gas chromatography, R. Gane (1934) found that the ripening causing volatile substance was ethylene. Ethylene was recognised as a plant hormone by Crocker *et al* (1935). Ethylene is produced in plants from the amino acid methionine. It is formed in almost all plant parts— roots, leaves, flowers, fruits, seeds (Denny and Miller, 1935). Maximum synthesis occurs during **climacteric ripening** of fruits and tissues undergoing senescence. Excess of auxin also induces ethylene synthesis. Many effects of excess auxin are actually the effects produced by ethylene.

Ethylene Functions

1. **Growth**. Ethylene inhibits longitudinal growth but stimulates transverse or horizontal growth and swelling of axis.

2. **Gravity**. It decreases the sensitivity to gravity. Roots become apogeotropic while stems turn positively geotropic. Leaves and flowers undergo drooping. The phenomenon is called **epinasty**. Seedlings develop tight **epicotyl hook**.

3. **Senescence**. It hastens the senescence of leaves and flowers.

4. **Abscission**. Abscission of various parts (leaves, flowers, fruits) is stimulated by ethylene which induces the formation of hydrolases.

5. **Apical Dominance**. Ethylene promotes apical dominance and prolongs dormancy of lateral buds.

6. **Breaking of Dormancy**. It breaks the dormancy of buds, seeds and storage organs.

7. **Abscisic Acid**. It seems that formation of abscisic acid in the leaves under conditions of water stress is mediated through ethylene.

8. **Growth of Rice Seedling**. Ethylene promotes rapid elongation of leaf bases and internodes in deep water rice plants. As a result leaves remain above water.

9. **Root Initiation**. In low concentration ethylene helps in root initiation, growth of lateral roots and root hairs. This increases the absorption surface of the plant roots.

10. **Fruit Ripening.** It aids in ripening of **climacteric fruits** and dehiscence of dry fruits. Climacteric fruits are fleshy fruits which show a sudden sharp rise of respiration rate at the time of ripening (respiratory climacteric). They are usually transported in green or unripe stage. Ethylene is used to induce artificial ripening of these fruits, *e.g.*, Apple, Mango, Banana, etc.

11. **Flowering.** It stimulates flowering in Pineapple and related plants as well as mango though in other cases the gaseous hormone causes fading of flowers. This helps in synchronising fruit set.

12. **Sex Expression.** Like auxins and cytokinins, ethylene has a feminising effect on sex expression. The genetically male plants of *Cannabis* can be induced to produce female flowers in the presence of ethylene. The number of female flowers and hence fruit is enhanced in monoecious plants like Cucumber.

Ethylene Uses

Ethylene regulates a number of physiological processes. Therefore, it is widely used PGR in agriculture. The common compound used for obtaining ethylene is **ethophen** or ethrel which is 2-chloroethyl phosphonic acid. In aqueous solution, ethophen is readily absorbed and transported to various parts. It releases ethylene slowly. The various commercial uses of ethylene are as follows :

1. **Fruit Ripening.** Kerosene lamps and hay were previously used for stimulating colour development and ripening of some fleshy fruits, *e.g.*, Banana, Mango, Apple, Tomato. The effect is due to ethylene. Ethylene lamps are now specifically used for this purpose.

2. **Feminising Effect.** External supply of very small quantity of ethylene increases the number of female flowers and hence fruits in Cucumber.

3. **Sprouting of Storage Organs.** Rhizomes, corms, tubers, seeds (*e.g.*, Peanut) and other storage organs can be made to sprout early by exposing them to ethylene.

4. **Thinning.** Excess flowers and young fruits are thinned with the help of ethylene, *e.g.*, Cotton, Cherry, Walnut. It allows better growth of remaining fruits.

ABSCISIC ACID

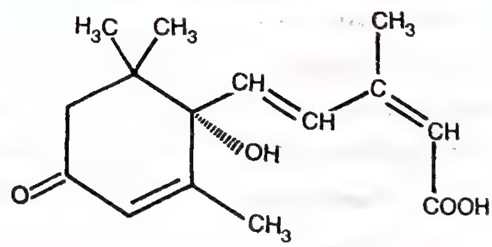


Fig. 15.27. Abscisic acid.

It is also called **stress hormone** because the production of hormone is stimulated by drought, water logging and other adverse environmental conditions. Abscisic acid is known as **dormin** as it induces dormancy in buds, underground stems and seeds. Its other names are abscissin II and inhibitor–B. *Abscisic acid is a mildly acidic dextro-rotatory cis sesquiterpene growth hormone which functions as a general growth inhibitor by counteracting other hormones (auxin, gibberellins, cytokinins) or reactions mediated by them.* The hormone was first isolated by Addicott *et al* (1963) from Cotton bolls. It is produced in many parts of the plants but more abundantly inside the chloroplasts of green cells. The hormone is formed from mevalonic acid or xanthophyll. It is transported to all parts of the plant through diffusion as well as transport channels (phloem and xylem).

Abscisic Acid Functions

1. **Bud Dormancy.** Abscisic acid induces dormancy of buds towards the approach of winter.

2. **Seed Dormancy**. It is mainly caused by abscisic acid. Dormancy allows seeds to tolerate desiccation and extremes of temperature better. The buds as well as seeds sprout only when abscisic acid is overcome by gibberellins. Because of its action in inducing dormancy, abscisic acid or ABA is also named as **dormin**.

3. **Stoppage of Cambium Activity**. Formation of abscisic acid stops mitosis in vascular cambium towards the approach of winter.

4. **Abscission**. Abscisic acid promotes abscission of flowers and fruits.

5. **Leaf Senescence**. Its excessive presence stops protein and RNA synthesis in the leaves and hence stimulates their senescence (leaf fall is actually promoted by ethylene).

6. **Transpiration**. During desiccation and other stresses, abscisic acid is rapidly synthesised. The inhibitor causes closure of stomata and hence prevents transpiration.

7. **Resistance**. Abscisic acid increases resistance of plants to cold and other types of stresses. It is, therefore, also known as **stress hormone**.

8. **Starch Hydrolysis**. Abscisic acid inhibits gibberellin mediated amylase formation during germination of cereal grains.

9. **Flowering**. In small quantities, abscisic acid is known to promote flowering in some short day plants, *e.g.*, Strawberry, Black Currant.

10. **Parthenocarpy**. ABA has been found to induce parthenocarpic development in Rose.

11. **Rooting**. Rooting of stem cuttings is promoted in some cases by abscisic acid, *e.g.*, Bean, Ivy, *Poinsettia* (= *Euphorbia pulcherrima*).

12. **Membrane Potential**. ABA induces a positive surface potential on cell membrane.

13. **Controlled Growth**. It is antagonist to gibberellins and counteracts the effect of other growth promoting hormones (auxins and cytokinins) and therefore, keeps their activity under check. By controlling growth, ABA plays an important role in seed development and seed maturation. Normally it inhibits seed germination, growth of excised embryos, growth of Duckweed and other plants.

Abscisic Acid Uses

1. **Antitranspirant**. Application of minute quantity of abscisic acid to leaves shall reduce transpiration to a great extent through partial closure of stomata. It conserves water and reduces the requirement of irrigation. Photosynthesis is reduced to a lesser extent (Transpiration 56%: Photosynthesis 14%).

2. **Flowering**. It is useful in introducing flowering in some short day plants kept under unfavourable photoperiods.

3. **Rooting**. Use of abscisic acid promotes rooting in many stem cuttings.

4. **Dormancy**. Abscisic acid can be used in prolonging dormancy of buds, storage organs and seeds.

Differences between Abscisic Acid and Gibberellic Acid/Cytokinin

Abscisic Acid	*Gibberellic Acid / Cytokinin*
1. It inhibits growth.	1. It promotes growth.
2. Abscisic acid promotes dormancy of seeds, buds and tubers.	2. The hormone overcomes the natural dormancy of seeds, bulbs, tubers, etc. and allows them to germinate.
3. It promotes flowering in some short day plants.	3. It promotes flowering in some long day plants.

4. The inhibitor decreases the synthesis of RNA and protein. It can even cause their degradation.	4. The hormone promotes synthesis of RNAs and proteins.
5. Abscisic acid promotes stomatal closure.	5. It helps in opening of stomata.
6. It prevents amylase activity.	6. It promotes amylase activity as during germination of cereal grains.
7. Abscisic acid causes abscission of flowers and fruits.	7. The hormone promotes development of fruits.
8. It promotes leaf senescence.	8. It prevents leaf senescence.
9. Abscisic acid promotes rooting of cuttings in some plants.	9. Gibberellic acid has no role in rooting.
10. It has no role in sexuality of flowers.	10. The hormone can bring about change in sexuality of flowers.

Interaction Among Growth Regulators

Growth, differentiation and development processes of plants are found to be regulated by two or more phytohormones acting synergetically or antagonistically. Cell division is promoted by both auxin and cytokinins acting synergetically. Cell growth is controlled by auxins, gibberellins and cytokinins. Morphogenesis is an interplay of auxins and cytokinins where both must be present in some minimum concentration. When auxin is in excess, roots differentiate on the callus while buds develop in the presence of excess cytokinin. Auxin causes apical dominance while cytokinins overcome the same. Auxin, cytokinins and ethylene have feminising effect on dioecious and monoecious plants. Gibberellins induce the production of male flowers in such plants. Cytokinins and auxins prevent senescence which is stimulated by abscisic acid and ethylene. Abscisic acid antagonises the effect of auxin, gibberellins and cytokinins or growth. It promotes flowering in some short day plants while gibberellins do so in some long day plants. Cytokinins cause stomata to open while abscisic acid results in their closure. Dormancy of buds and seeds is mostly due to abscisic acid. The same is broken by gibberellins. Cambial activity and fruit growth seem to require auxin, gibberellins and cytokinins. ABA checks the same.

Photoperiodism

The effect of photoperiods or daily duration of light hours (and dark periods) on the growth and development of plants, especially flowering, is called photoperiodism. Photoperiodism was first studied by Garner and Allard (1920). They observed that 'Maryland Mammoth' variety of Tobacco could be made to flower in summer by reducing the light hours with artificial darkening. It could be made to remain vegetative in winter by providing extra light.

On the basis of photoperiodic response to flowering, plants have been divided into the following categories :

(a) **Short Day Plants** (SDP, Fig. 15.28). They flower when the photoperiod or day length is **below a critical period***. Most of winter flowering plants belong to this category, *e.g., Xanthium* (Cocklebur), *Chrysanthemum, Cosmos bipinnatus, Aster, Dahlia*, Rice, Sugarcane, Strawberry, Potato, Tobacco, Soya Bean varieties.

* Critical photoperiod is that continuous duration of light which must not be exceeded in short day plants and should always be exceeded in long day plants in order to bring them to flower. There is no relation with the total day length. For example, the critical photoperiod for short day plant *Xanthium* is 15.6 hrs while the same for long day plant of Oat is only 9.0 hours.

(b) **Long Day Plants** (LDP, Fig. 15.28). These plants flower when they receive long photoperiods or light hours which are **above a critical length**, *e.g.*, Henbane (*Hyoscyamus niger*), Wheat, Oat, Sugar Beet, Spinach (*Spinacea oleracea*), Radish, Barley, Larkspur, Lettuce.

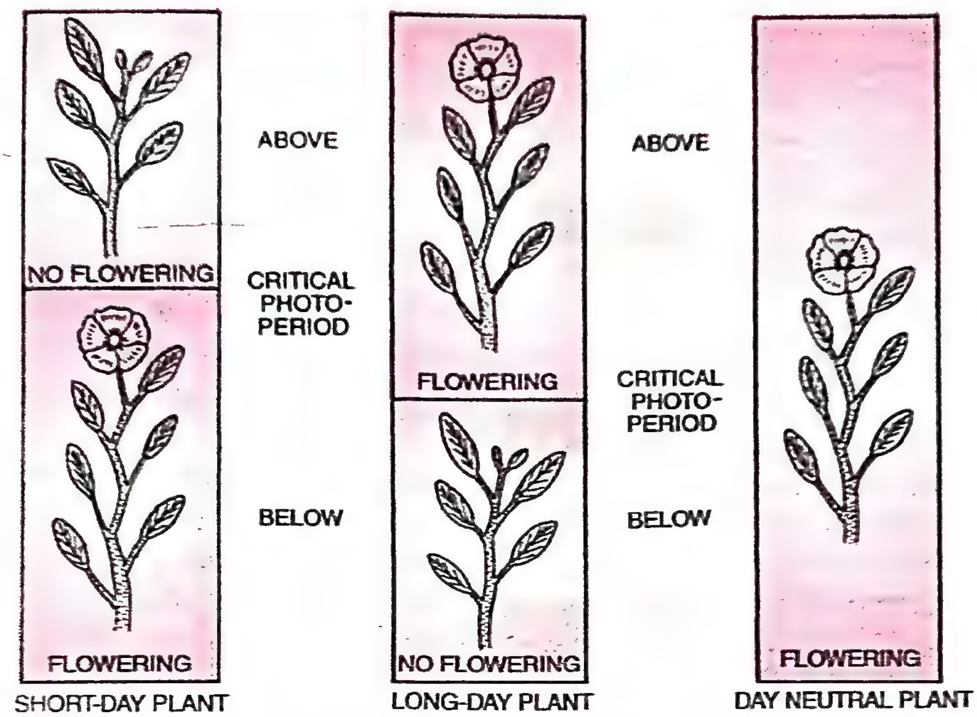


Fig. 15.28. Three major types of photoperiodic behaviour for flowering.

(c) **Short-Long Day Plants** (S-LDP). The plants require short photoperiods for floral initiation and long photoperiods for blossoming. They usually come to flower between spring and summer, *e.g.*, *Campanula medium*, Petkus variety of Rye.

(d) **Long Short Day Plants** (L-SDP). The plants require long photoperiods for floral initiation and short photoperiods for blossoming. The plants flower between summer and autumn, *e.g.*, *Bryophyllum*, *Cestrum*.

(e) **Intermediate Day Plants** (IDP). The plants flower within a definite range of light hours. Flowering does not take place above and below this range, *e.g.*, Wild Kidney Bean.

(f) **Day Neutral or Indeterminate Plants** (DNP). The plants can blossom throughout the year, *e.g.*, Tomato, Pepper, Cucumber, Pea varieties, Sunflower, Maize, Cotton, etc.

Dark Periods (Skotoperiods). Short day plants are also called **long night** plants because they require a continuous **critical dark period**, which must be exceeded. If the plant is exposed to even a flash of light (red, usually 660 nm) before achieving a critical dark period, flowering is prevented (Hamner and Bonner, 1938; Fig. 15.29). It is called **light break reaction**. Red light effect can, however, be prevented by immediately providing far-red light. Red, far-red exposures given in succession show that plant response is determined by the last exposure. It is, therefore, clear that photoperiodic response is mediated by **phytochrome** which shows reversible change in red (660 nm) and far-red (730 nm) wavelength.

In long day plants, the period of darkness should be shorter than a critical dark period. Light exposure during dark does not inhibit flowering in long day plants. Rather it promotes flowering. They also come to flower in alternate short light and still shorter dark periods. Long day plants can flower even when exposed to continuous light. Hence long day plants are also called **short night plants.**

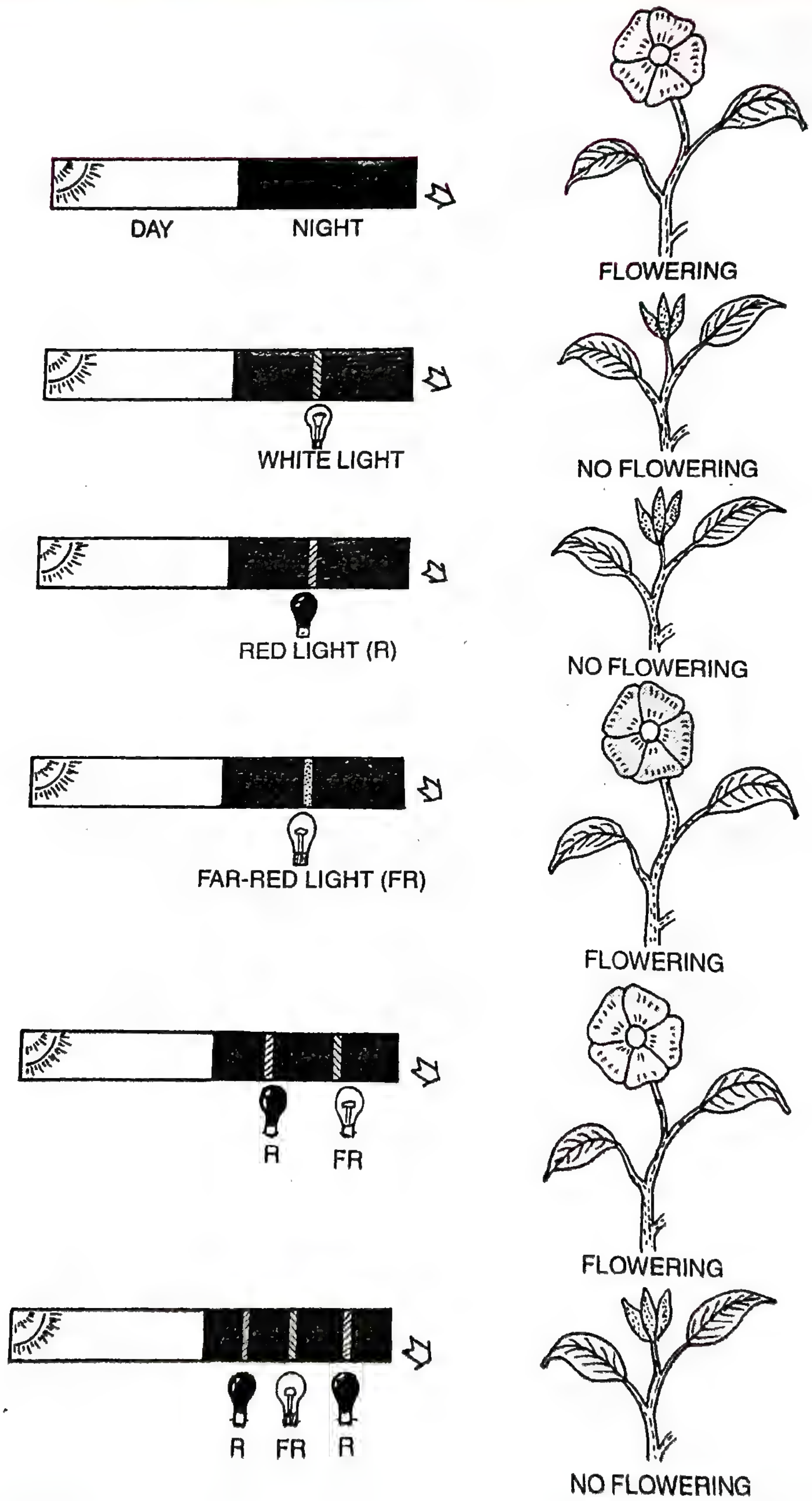


Fig. 15.29. Effect of interruption of skotoperiod in a short day plant by light of different types.

Differences between Short Day and Long Day Plants

Short Day Plants	*Long Day Plants*
1. Plants are induced to flower by photoperiods below a critical length.	1. The plants come to flower after receiving photoperiods above a critical length.
2. Short day plants are also called **long night plants** because they require darkness above a critical level.	2. Long day plants are also called **short night plants** because they require darkness below a critical level.
3. Plants do not flower under long day conditions as the critical dark period is not achieved.	3. Plants do not flower under short day conditions as the dark period is above the critical length.
4. Plants can flower in complete darkness if supplied with exogenous nutrients.	4. Plants cannot flower under complete darkness. They can, however, do so in continuous light.
5. Flowering is prevented if dark period below the critical level is interrupted by a flash of light.	5. Flowering is stimulated if dark period is interrupted by light.
6. Interruption of light by dark does not inhibit flowering.	6. Interruption of light by dark inhibits flowering under normal photoperiods.
7. They do not flower under alternate short light and dark periods.	7. Long day plants come to flower under alternating short cycles of light and darkness.
8. Supply of gibberellins does not induce flowering (exception — Balsam) under non-inductive photoperiods.	8. Supply of gibberellins induces flowering in many cases under non-inductive photoperiods.
9. Abscisic acid promotes flowering in some cases.	9. Abscisic acid does not promote flowering.
10. Short day plants flower in autumn-spring periods.	10. Long day plants flower in late spring-summer periods.

Photoperiodic Perception. Photoperiodic stimulus is picked up by the fully developed leaves (Knott, 1934). Even one leaf or a part of it (upto 1/8) is sufficient for this purpose (Fig. 15.28). Very young or first few leaves (7 leaves in *Xanthium strumarium*) are commonly insensitive. However, in *Pharbitis nil* (Japanese Morning Glory and *Chenopodium rubrum* (Pigweed) even the cotyledons can perceive the stimulus.

Experiment (Fig. 15.30). Grow a number of seedlings of *Xanthium strumarium* (Cocklebur) under long day conditions (16 hours light day) till they develop more than eight mature leaves. Now divide the seedlings in the following six lots and expose to the light hours indicated.

Seedling	Photoperiod	Result
1. Normal Seedling	12 hrs (short day)	Flowering
2. Seedling with one leaf intact	12 hrs (short day)	Flowering
3. Defoliated Seedling	12 hrs (short day)	No Flowering
4. Defoliated Seedling	16 hrs (long day)	No Flowering
5. Seedling with one leaf intact	16 hrs (long day)	No Flowering
6. Normal Seedling	16 hrs (long day)but one leaf covered for 4 hrs daily.	Flowering

The result clearly shows that *Xanthium* is short day plant and that the stimulus of favourable photoperiod is perceived by leaves. At least one leaf must be kept under inductive photoperiod.

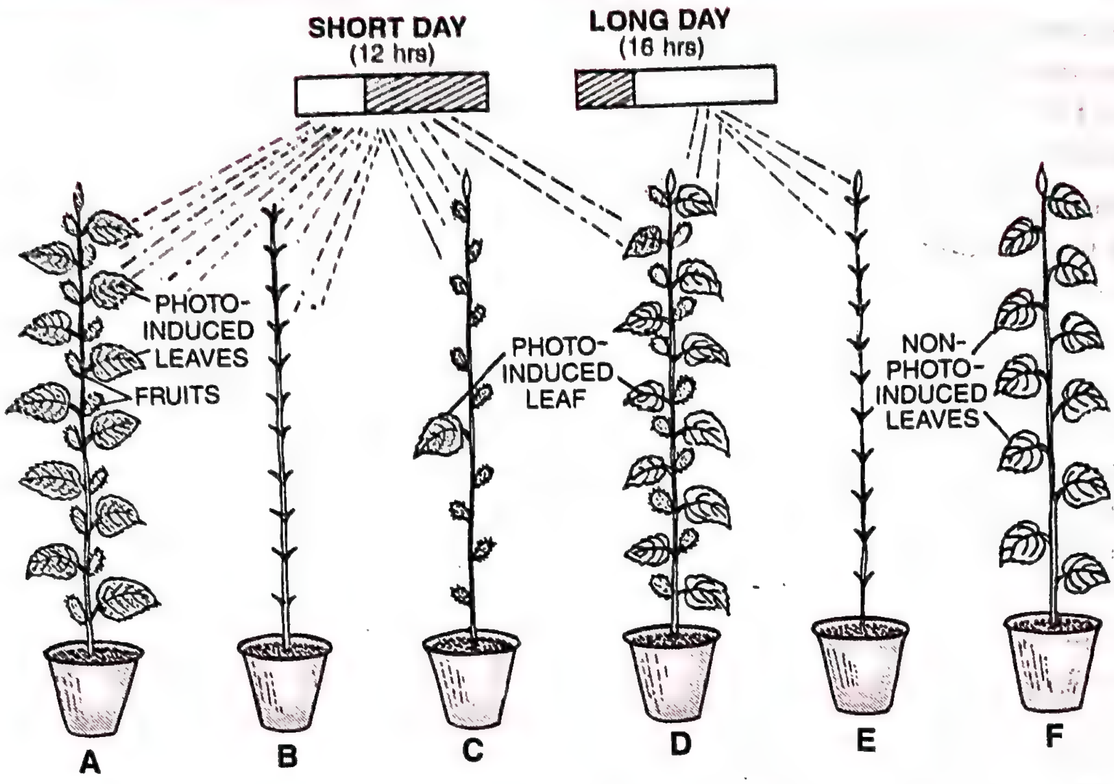


Fig. 15.30. Demonstration to show that the photoperiodic induction is received by leaves. A, leaves under suitable photoperiod. B, no leaves, no induction. C, a single leaf under suitable photoperiod. D, only one leaf is exposed to suitable photoperiod while the other leaves are under unsuitable photoperiod. E, no leaves. F, leaves under noninductive photoperiod.

Photoperiodic Induction. It generally occurs when the plant has achieved certain minimum vegetative growth, *e.g.*, 8 leaves in *Xanthium strumarium*. Minimum vegetative growth provides the plant with **ripeness to flower**. Exceptions are found in *Pharbitis nil* and *Chenopodium rubrum* where the seedlings can be photo-induced even in their cotyledonary stage.

The minimum number of appropriate photoperiods required for induction varies from one (*e.g., Xanthium, Pharbitis*) to 25 (*e.g., Plantago lanceolata*).

Photoreceptor. The chemical which perceives the photoperiodic stimulus in leaves is blue coloured cytoplasmic chromoprotein called **phytochrome**. Besides regulating photoperiodic responses, it takes part in dormancy, seed germination and photomorphogenesis.

Mechanism. Soon after perceiving the required favourable photoperiods, the leaves produce

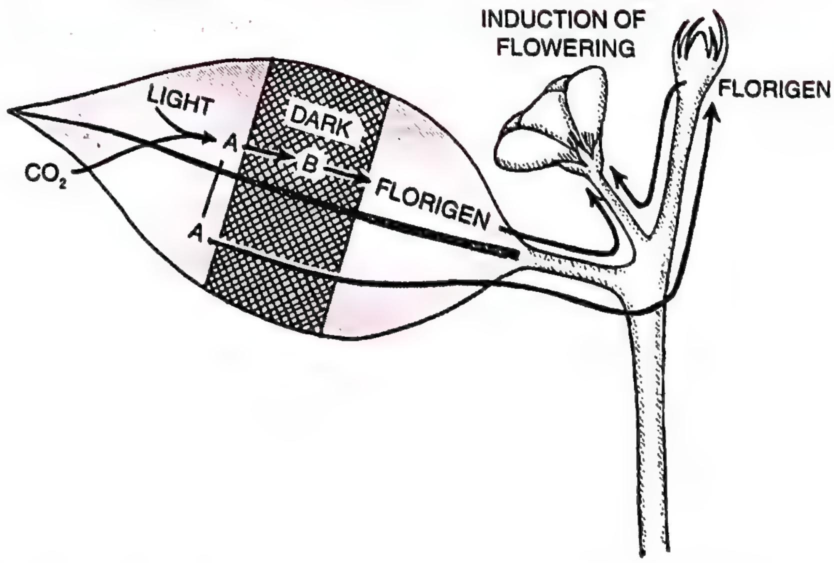


Fig. 15.31. Photoperiodic induction and formation of florigen which is translocated to growing point for formation of flowers.

a chemical which stabilises in dark. It is then passed over to the shoot apex which undergoes differentiation to produce flowers (Fig. 15.31).

The chemical which induces flower formation has been named as **florigen**. It has not yet been identified. By grafting experiments, it has been found that the stimulus of flowering can pass from the induced plant to the non- induced plant even if the latter is growing under unfavourable photoperiods.

There are two different mechanisms of floral induction in long day and short day plants. In long day plants, the signal from long photoperiods induces the formation of a globular protein called **FT** (Corbester *et al* 2007). It is passed to apical meristem through and form another protein called **FD** (Abe *et al* 2003). FD activates floral genes.

In short plants, short photoperiods produce a protein called Hd 3a. It counteracts flowering inhibitor, passes into shoot apex to activate floral genes (Blazquez 2005).

Experiment (Fig.15.32). Grow a few seedlings of *Xanthium strumarium* (Cocklebur) under long day conditions (16 hrs light per day) till they develop eight or more leaves. Now divide the seedlings in two lots. Expose one lot to short day conditions (12 hrs light + 12 hrs darkness) while keep the other lot under long day conditions. The lot exposed to short day conditions shall soon develop flowers while flowering does not occur in plants exposed to long day conditions. Approach grafting is performed between two plants, one exposed to short day conditions while the other is exposed to long day conditions. Both of them will come to flower showing that the stimulus of flowering is a chemical (florigen) which can be transferred or translocated from one plant to another through the graft.

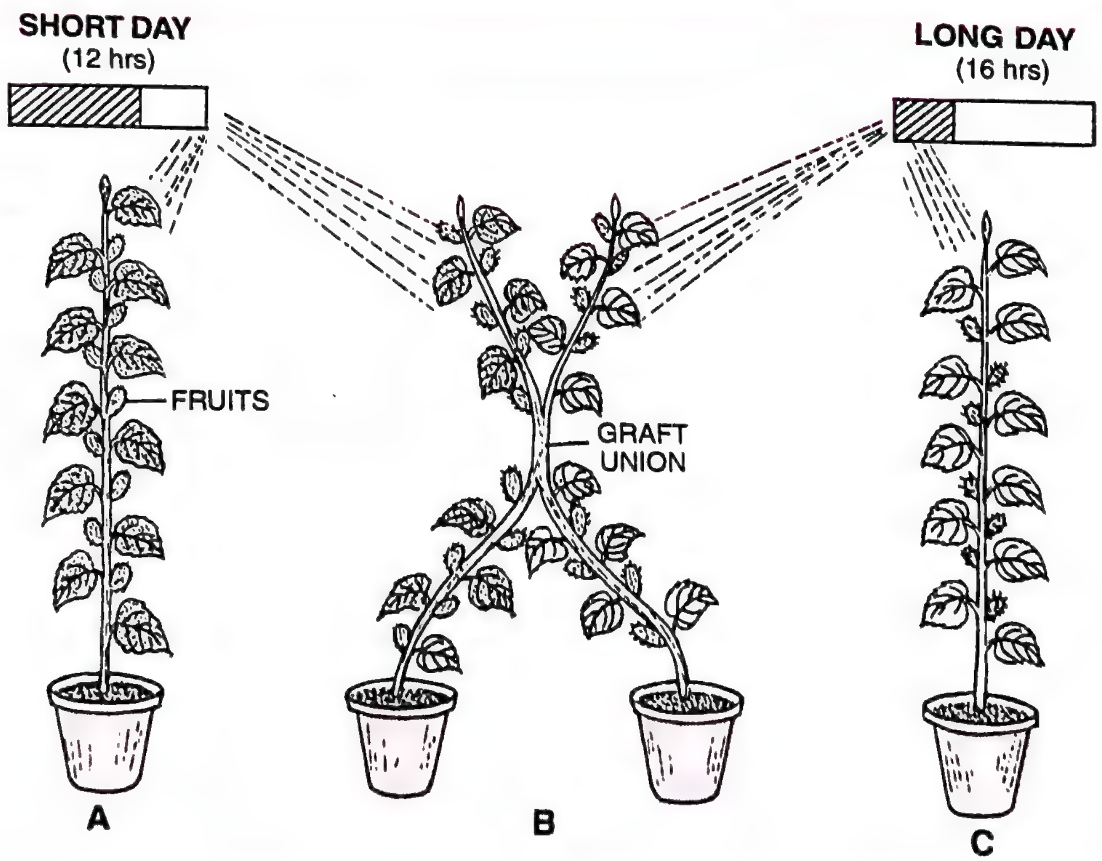


Fig. 15.32. Demonstration through grafting showing that flower inducing stimulus is a chemical.

Differences between Florigen and other Hormones

Florigen	*Other Hormones*
1. It is a hypothetical hormone which has not yet been extracted.	1. The hormones are known chemicals.
2. It is produced in response to specific photo-periodicity typical of a plant type.	2. No hormone is known which is induced in response to photoperiods or skotoperiods.
3. Florigen is the same though different groups of plants require different photo-periodicities.	3. Such a varied parameter is not applicable to any of the hormones.
4. It induces only flowering. Growth is neither inhibited nor stimulated.	4. Other hormones may or may not induce flowering in some of the plants.
5. It is produced by the joint activity of leaves and growing points.	5. They are not synthesized by joint activity of two organs.
6. Florigen is produced only when the plants have completed juvenile stage.	6. They are produced even in juvenile stage.

Importance

(i) Photoperiodism determines the season in which a particular plant shall come to flower. For example, short day plants develop flowers in autumn-spring period (*e.g., Dahlia, Xanthium*) while long day plants produce flowers in summer (*e.g., Amaranthus*). Day neutral plants can be made to flower throughout the year since their flowering is dependent more on temperature and vegetative growth (*e.g.,* Tomato).

(ii) Knoweldge of photoperiodic effect is useful in keeping some plants in vegetative growth (many vegetables) to obtain higher yield of tubers, rhizomes, etc. or keep the plant in reproductive stage to yield more flowers and fruits.

(iii) A plant can be made to flower throughout the year under green house conditions if a favourable photoperiod is being provided to it. This has been used by commercial growers to meet the demands of market for prized vegetables and flowers.

(iv) The phenomenon has helped the plant breeders in effecting cross-breeding in plants which normally develop flowers in different seasons.

(v) It has further been found that photoperiodic response of plants is under the control of genes. Manipulation of genes can enable a plant to flower in different seasons. This has actually been achieved by National Botanical Research Institute, Lucknow. The institute has developed varieties of *Chrysanthemum* which flower in different months of the year.

(vi) A proper knowledge of photoperiodism in relation to flowering is also highly useful in laying out gardens, orchards and planning crop pattern of the area.

Vernalization

Many plants do not come to flower before they experience a low temperature. These plants remain vegetative during the warm season, receive low temperature during winter, grow further and then bear flowers and fruits. Requirement of low temperature prevents precocious reproductive development in autumn. It allows the plant to reach vegetative maturity before reproduction can occur. The condition occurs in winter varieties of some annual food plants (*e.g.,* Wheat, Barley, Rye), some biennial (*e.g.,* Cabbage, Sugarbeet, Carrot) and perennial plants (*e.g.,* Chrysanthemum). The annual winter plants also possess spring varieties. The spring varieties are planted in spring. They come to flower and bear fruits prior to end of growing season. If the winter varieties are sown similarly, they fail to

flower and produce fruits before the end of growing season. They are planted in autumn, form seedlings in which form they cover winter. The seedlings resume growth in spring. They bear flowers and fruits in summer.

It was found by Lysenko (1928), a Russian worker, that the cold requiring annual and biennial plants can be made to flower in one growing season by providing low temperature treatment to young plants or moistened seeds. He called the effect of this chilling treatment as **vernalization.** *Vernalization is, therefore, a process of shortening of the juvenile or vegetative phase and hastening flowering by a previous cold treatment* (Fig. 15.33).

Site for Vernalization. The stimulus of vernalization is perceived only by the meristematic cells, *e.g.*, shoot tip, embryo tips, root apex, developing leaves, etc. (Wellensiek, 1964).

Requirements of Vernalization. (i) **Low Temperature.** Low temperature required for vernalization is usually 0°–5°. It is 3°–17° in case of biennial Henbane (*Hyoscyamus niger*). Low temperature treatment should not be immediately followed by very high temperature (about 40°C) otherwise the effect of vernalization is lost. The phenomenon is called devernalization. (ii) **Period of Low Temperature Treatment.** It varies from a few hours to a few days. (iii) **Actively Dividing Cells.** Vernalization does not occur in dry seeds. The seeds must be germinated so that they contain an active embryo. For this the seeds are moistened before exposing them to low temperature. In whole plants, an active meristem is required. (iv) **Water.** Proper protoplasmic hydration is must for perceiving the stimulus of vernalization (v) **Aerobic Respiration** and (vi) **Proper Nourishment.**

Mechanism. The stimulus received by the actively dividing cells of shoot or embryo tip travels to all parts of the plant

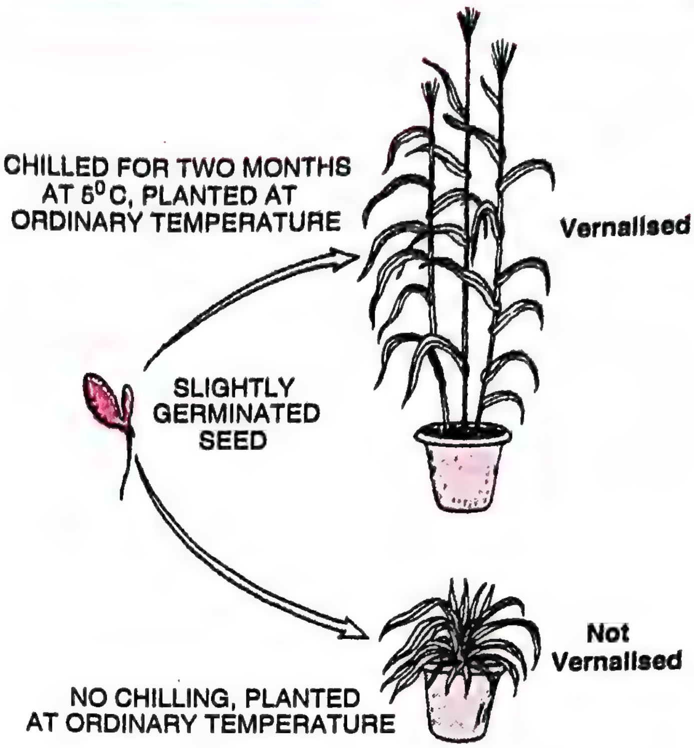


Fig. 15.33. Experiment to show effect of vernalization on Winter Rye.

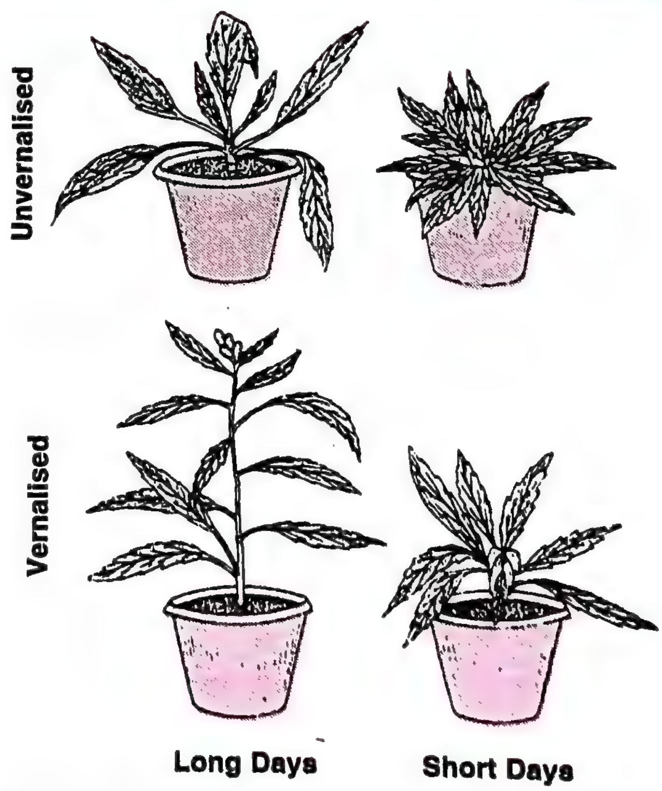


Fig. 15.34. Effect of vernalization and photoperiods on Henbane.

and prepare it to flower. The stimulus has been named as **vernalin**. It can be passed from one plant to another through grafting in case of Henbane but not in others. However, the chemical has not been separated. In some plants cold treatment can be replaced by gibberellins.

Vernalization prepares the plant to flower. The induction of flowering depends upon the presence of other favourable conditions. Photoperiodism, however, not only prepares the plant to flower but also brings about flowering. Thus, Henbane is a long-day plant which also requires cold treatment. Unless and until both are provided the plant will not come to flower (Fig. 15.34).

Importance. (i) Vernalization can help in **shortening** the juvenile or vegetative period of plant and bring about early flowering. It is not only applicable to temperate plants but also to some tropical plants, *e.g.*, Wheat, Rice, Millets, Cotton. (ii) It increases yield, resistance to cold and diseases. (iii) Kernel wrinkles of *Triticale* can be removed by vernalization.

Differences between Vernalization and Photoperiodism

Vernalization	*Photoperiodism*
1. It is the process of making a plant receptive for flowering stimulus by a previous cold treatment.	1. It is the process of stimulating floral formation by relative lengths of day and night.
2. Vernalization brings about ripeness to flower.	2. Photoperiodism has no role in bringing about ripeness to flower.
3. It has no role in inducing flowering.	3. Photoperiodism induces a plant to flower.
4. Vernalization treatment is often prolonged.	4. Photoperiodic induction requires treatment for only a few days.
5. Low temperature treatment must be applied throughout day and night.	5. Photoperiodic induction is interrupted by dark periods.
6. The stimulus of vernalization is perceived by dividing cells, *e.g.*, shoot tips, embryo tips.	6. The stimulus of photoperiodism is perceived by leaves.
7. It is believed to be mediated by a chemical called vernalin.	7. Photoperiodism produces a chemical florigen for inducing flowering.
8. The stimulus of vernalization cannot be transferred to nonvernalized plants with the exception of Henbane.	8. The stimulus of photoperiodic induction can be transferred to non-induced plants through grafting.
9. The effect of vernalization can be reversed by application of high temperature immediately after cold treatment.	9. The effect of photoperiodism cannot be reversed.
10. Gibberellins replace the low temperature requirement in many plants.	10. Gibberellins can replace long day photoperiods in some plants.
11. The exact chemical perceiving the cold treatment is not known.	11. Phytochrome is the chemical that perceives the stimulus of light.
12. It is applicable to temperate and some tropical plants.	12. It is applicable to plants found all over the world.

SEED DORMANCY

Seed dormancy or **rest** is the innate inhibition of germination of a viable seed even placed in most favourable environment for germination. Bewlay and Black (1994) have divided seed dormancy into two categories, seed coat based and embryo based. Germination inhibitors occur in both.

Reasons

1. **Immaturity of Embryo.** Embryo is immature at the time of seed shedding. The seed will remain dormant till the embryo becomes mature, *e.g.*, *Anemone nemorosa, Ranunculus ficaria.*

2. **After-Ripening.** The seeds require a period of dry storage for developing the ability to germinate, *e.g.*, Wheat, Oat, Barley.

3. **Impermeable Seed Coat.** The seed coat is impermeable to water and gases, *e.g.*, Apple, *Chenopodium.*

4. **Hard Seed Coat.** The seed coat is mechanically resistant and does not allow the embryo to grow, *e.g.*, *Amaranthus, Lepidium.*

5. **Germination Inhibitors.** They occur in the seed coats and cotyledons of the embryos. The important germination inhibitors causing seed dormancy are abscisic acid, phenolic acid, ferulic acid, coumarin, short fatty acids and cyanogenic chemicals, *e.g.*, Apple, Peach, Ash, *Cucurbita, Iris, Xanthium.*

Natural Breaking of Seed Dormancy

In nature seed dormancy is broken automatically due to (i) Development of **growth** hormones to counter growth inhibitors. (ii) Leaching of germination inhibitors. (iii) Maturation and after-ripening of embryo. (iv) Weakening of impermeable and tough seed coats by microbial action, abrasion, passage through digestive tract of animals, etc.

Artificial Breaking of Seed Dormancy

1. **Scarification.** Hard, impermeable seed coat is weakened or ruptured by filing, chipping, hot water and chemicals.

2. **Stratification.** Seeds are moistened and exposed to oxygen for variable period at low or high temperature.

3. **Counteracting Inhibitors.** Inhibitors are destroyed by dipping seeds in KNO_3, thiourea, ethylene chlorohydrin and gibberellin.

4. **Shaking and Pressure.** Vigorous shaking and hydraulic pressure are used to weaken seed coats.

Importance of Seed Dormancy

1. **Perennation.** Seed dormancy allows seeds to pass through drought, cold and other unfavourable conditions.

2. **Dispersal.** It is essential for dispersal of seeds.

3. **Germination Under Favourable Conditions.** Seeds germinate only when sufficient water is available to leach out inhibitors and soften the seed coats.

4. **Storage.** It is because of dormancy that human beings are able to store grains, pulses and other edibles for making them available throughout the year and transport to the areas of deficiency.

ADDITIONAL INFORMATION

- **Strasburger.** Studied phases of growth in a young root by marking it with India ink.
- **Inflexion Point.** The point at which exponential phase ends and decelerating phase begins.
- **Negative Growth.** The term is sometimes used for senescence.
- **Antiageing Plant Hormone.** Cytokinin.
- **Ascorbic Acid** (Vitamin C). Prevents over ripening and browning of cut fruits due to its being anti-oxidant.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Define : Growth, Differentiation, Development, Dedifferentiation, Redifferentiation, Determinate growth, Meristem, Growth Rate.

✓ **Growth.** It is a permanent or irreversible increase in dry weight, size, mass or volume of a living structure due to synthesis of new intracellular and extracellular materials.

Differentiation. It is the process of maturation by which a living cell or structure assumes a definite structure, chemistry and function.

Development. It is a series of changes that occur in the structure and functioning of cell, organ or organism during its life history.

Dedifferentiation. The process of despecialisation of differentiated cells so that they become undifferentiated and meristematic is called dedifferentiation, *e.g.,* Cork cambium.

Redifferentiation. The maturation of undifferentiated cells formed through dedifferentiation is called redifferentiation, *e.g.,* cork cells.

Determinate Growth. It is a limited growth that stops when an organ or organism reaches a certain size and shape, *e.g.,* leaves, flowers, fruits.

Meristem. It is a tissue, the cells of which are capable of division forming new cells and tissues of the plants, *e.g.,* apical meristem, intercalary meristem, lateral meristem.

Growth Rate (r). It is increase in size of a population or number and size of cells per unit time.

2. Why is not any one parameter good enough to demons trate growth through the life of a flowering plant ?

✓ A single parameter is used for demonstrating growth only when all organs of the organisms show similar type of growth. However, this is not so. Stem and root grow in length as well as girth. Initially, there is more growth in main stem or main root. Later on more growth occurs in their branches. Leaves grow in area while fruits grow in volume. Therefore, a single parameter is not good enough to demonstrate growth.

3. Describe briefly : (a) Arithmetic growth (b) Geometric growth (c) Sigmoid growth curve (d) Absolute and relative growth rates.

✓ **(a) Arithmetic Growth.** It is a type of growth in which the rate of growth is constant and increase in growth occurs in arithmetic progression, *i.e.,* 2, 4, 6, 8, 10, *e.g.,* growth of growing points.

(b) Geometric Growth. In this type, size or number increases in multiplicative fashion, *i.e.,* 2, 4, 8, 16, 32, etc., *e.g.,* growth of microorganisms in cultures having optimum nutrients and space.

(c) Sigmoid Growth Curve. It is an S-shaped graph produced on plotting growth against time. Sigmoid growth curve has four components — a slow lag phase, a rapid log or exponential phase, phase of diminishing growth and steady or stationary phase.

(d) (i) **Absolute Growth Rate.** It is total growth per unit time.

(ii) **Relative Growth Rate.** It is growth per unit time per unit initial growth.

4. List five main groups of natural plant growth regulators. Write a note on discovery, physiological functions and agricultural/horticultural applications of any one of them.

✓ Five types of natural plant growth regulators are auxins, gibberellins, cytokinins, abscisic acid and ethylene.

Auxins. For discovery (history), functions and applications (uses). Refer to the text.

5. What do you understand by photoperiodism and vernalisation ? Describe their significance.

✓ **Photoperiodism.** The effect of daily duration of light hours on the growth and development of plants, especially flowering is called photoperiodism. It was discovered by Garner and Allard (1920) first in case of Tobacco. Depending upon photoperiod required for flowering, plants are of six types— long day plants (LDP), short day plants (SDP), short-long day plants (SLDP), long-short day plants (LSDP), intermediate day plants (IDP) and day neutral or indeterminate plants (DNP).

Significance (Importance). Refer to the text.

Vernalization. It is the process of hastening flowering by a previous cold treatment. The technique of vernalisation was discovered by Lysenko (1928). Vernalisation requires low temperature, actively dividing cells, proper hydration, aerobic respiration and proper nourishment.

Importance. Refer to the text.

6. Why is abscisic acid also known as stress hormone ?

✓ Abscisic acid is called stress hormone because its production is stimulated by drought, water logging and other adverse conditions. (i) During drought, abscisic acid closes stomata and prevents

loss of water in transpiration. (ii) On the approach of adverse conditions abscisic acid induces dormancy of buds. (iii) It induces dormancy of seeds and vegetative propagules (*e.g.*, rhizome, tuber, corm, bulb) for perennation. (iv) Cold hardiness and resistance to infections develop through abscisic acid.

7. "Both growth and differentiation in higher plants are open". Comment.

✓ Plants are built on modular fashion where structure is never complete because their tips are **open ended** where growth and subsequently differentiation are continuously taking place. It is due to presence of meristems, shoot apical meristem (SAM) and root apical meristem (RAM). The cells of the meristems are dividing throughout the life of a plant. The cells formed by these meristems later differentiate into different types of tissues and organs.

8. "Both a short day and a long day plant can flower simultaneously in a given place". Explain.

✓ **Long day plants** are those plants which come to flower only when they receive photoperiods above a critical day length, *e.g.*, 9 hrs in Oat, 11 hrs in Henbane. **Shortday plants** come to flower only when they get light below a critical day length, *e.g.*, 15.6 hrs in *Xanthium*. At 9.5 hrs both Oat and *Xanthium* will be flowering sumultaneously. Similarly Henbane and *Xanthium* would be simultaneously flowering between 11 to 15.5 hrs.

9. Which one of the plant growth regulators would you use if you are asked to (a) Induce rooting in a twig (b) Quickly ripen a fruit (c) Delay leaf senescence (d) Induce growth in axillary buds (e) 'Bolt' a rosette plant (f) Induce immediate stomatal closure in leaves.

✓ **Induce Rooting in a Twig.** Indole butyric acid (IBA), Naphthalene acetic acid (NAA). They are auxins. The commercial root inducing hormone is called **rootone.**

(b) **Quickly Ripen a Fruit.** Ethylene. (c) **Delay Leaf Senescence.** Cytokinin. (d) **Induce Growth in Axillary Buds.** Cytokinin. (e) **Bolt a Rosette Plant.** Gibberellin. (f) **Induce Immediate Stomatal Closure in Leaves.** Abscisic acid (ABA).

10. Would a defoliated plant respond to photoperiodic cycle ? Why ?

✓ Leaf is the locus for photoperiodic perception. A defoliated plant will not be able to perceive the photoperiod stimulus. It will, therefore, be unable to respond to photoperiodic cycle.

11. What would be expected to happen if :

(a) GA_3 is applied to rice seedlings. (b) Dividing cells stop differentiating. (c) A rotten fruit gets mixed with unripe fruits. (d) You forget to add cytokinin to the culture medium.

✓ **(a) GA_3 is Applied to Rice Seedlings.** The plants will show extra elongation (bakane disease). They may also remain sterile.

(b) Dividing Cells Stop Differentiating. A callus (in culture medium) or tumour of undifferentiated cells will be produced.

(c) A Rotten Fruit Gets Mixed With Unripe Fruits. The rotten fruit emits ethylene which will hasten ripening of unripe fruits.

(d) You Forget to Add Cytokinin to the Culture Medium. There will be very little growth as cytokinin is not only essential for cell division but also for differentiation of shoot.

TEST QUESTIONS

One Mark Questions (With Answers)

1. In wheat field some broad-leaved weeds were seen by a farmer. Which plant hormone would you suggest to get rid of the same ?

✓ 2 : 4-D and 2 : 4 : 5 T

2. Which growth is also called apparent growth ?

✓ Irreversible increase in mass or volume is an external manifestation of growth. It is also called **apparent growth.**

3. Do gibberellins also promote rooting ?

✓ No

4. Name any one hormone which increases femaleness in plants ?

✓ Anxins, Cytokinins and Ethylene.

5. How light affects germination in Pea and Onion seeds ?

✓ In Pea seeds germination is hastened by the presence of light. Light inhibits germination in the seeds of Onion.

6. Which plant hormone is named anti-ageing hormone ?
   ✓ Cytokinins.

One Mark Questions (Without Answers)

1. Expand the terms: NAA, IAA, SDP, DNP, GA, 2,4-D, ABA, P_{fr}.
2. Name the hormone that was discovered from (a) Urine (b) DNA degradation product (c) Cotton bolls (d) Fungus.
3. A culture medium having callus grown from tobacco pith, is supplied with more of cytokinins than auxins. It will result in the development of (a) tap root (b) shoot bud (c) bulbil (d) flower bud.
4. Name the synthetic auxins used for inducing the rooting in woody plants.
5. A student cultures a callus from the tobacco pith in a sterilised minimal nutritive medium but adds more cytokinins than auxins. What would develop first from callus— shoot, buds or the roots ?
6. A farmer grows cucumber plants in his field. He wants to increase the number of female flowers in them. Which plant growth regulator can be applied to achieve this.
7. Which plant hormone helps in ripening of fruits ?
8. What is growth ?

Two Mark Questions (With Sample Answers)

1. What are the important characteristics of growth ? Describe in brief.
2. "The role of ethylene and abscisic acid is both positive and negative". Justify the statement.
3. What is growth curve ?
   ✓ It is the graphic representation of the total growth against time. The period or time, in which growth takes place. has been called grand period of growth by Sachs (1873). The rate of growth is not uniform during the grand period of growth. If total growth is plotted against time, an S-shaped or sigmoid curve is obtained. It consists of four parts — lag phase, log phase (exponential phase), phase of diminishing growth and stationary phase (steady growth for organs or oganisms of indefinite growth).
4. What do you understand by growth regulators and phytohormones ?
   ✓ Growth regulators are organic substances, other than nutrients, which in low concentration regulate growth, differentiation and development by promoting or inhibiting the same. One type of plant growth regulators are **plant hormones** or **phytohormones**. Technically a plant hormone is a chemical substance produced naturally in plants is translocated to another region for regulating one or more physiological reactions when present in low concentration.
5. List any four uses of auxins.
6. Name a plant hormone that can never act alone. List any three activities of this hormone in conjuction with auxins.
7. Name the plant hormone that inhibits plant growth and metabolism. What is the role of this hormone in seed development.
8. Give at least four roles of gibberellins on plant growth.
9. What is abscission zone ? Name its components and their functions.
10. What is sigmoid growth curve ? Why is it so called ?
11. Where are auxins synthesised in plants ? Mention any two of their functions.

Three Mark Questions (Short Answer Type)

1. What are the different phases of growth ? Give characteristics of each.
2. What are weedicides ? Give their effect on the ecology of a place.
3. Which hormone prevents senescense ? Name its different functions and uses.
4. Name the only gaseous natural plant hormone. Describe its three different kinds of action in plant.
5. Write a brief account of abscisic acid.
6. Name two synthetic auxins. Give four functions of auxins.
7. Which parts of the plant produce gibberellin ? State two functions of this hormone and mention why it was named gibberellin ?
8. Name the plant hormone which was discovered from fungus. Give its any four functions.

Five Marks Questions (Long Answer Type)

1. Describe an experiment that would demonstrate that growth stimulating hormone is produced at the tip of coleoptile.

2. Explain different phases of growth with the help of diagram.
3. How will you measure the rate of growth ? Describe an instrument used to measure the increase in height of an angiospermic plant.

Multiple Choice Questions (With Answers)

(1) Auxanometer is used to measure
(a) Growth in length (b) growth in breadth (c) pest population (d) both **a** and **b**. *(JKCMEE 2011)*

(2) Natural cytokinins are synthesised in tissues for
(a) differentiating (b) senescent (c) dividing (d) storing food. *(DPMT 2011)*

(3) Hormone antagonist to gibberellins is (a) IAA (b) ABA (c) Zeatin (d) Ethylene. *(CBSE Mains 2012)*

(4) Vernalisation stimulates flowering in
(a) Carrot (b) Ginger (c) Zamikand (d) Turmeric. *(CBSE Mains 2012)*

(5) Which can prevent, premature fruit fall (a) GA_3 (b) Zeatin (c) Ethylene (d) NAA. *(J K CET 2013)*

(6) During seed germination, its stored food is mobilised by
(a) Gibberellin (b) Ethylene (c) Cytokinin (d) ABA. *(NEET 2013)*

(7) Spraying sugarcane crop with a plant hormone increases length of plants and increases yield by as much as 20 tonnes per acre. The hormone is (a) Gibberellin (b) Auxin (c) Cytokinin (d) ABA. *(AMU 2014; Kerala 2014)*

(8) A few normal seedlings of Tomato were kept in the dark room. After a few days they were found to become white coloured like albinos. Which of the following terms will you use to describe them?
(a) Embolised (b) Etiolated (c) Defoliated (d) Mutated. *(CBSE 2014)*

(9) Botting means (a) Elongation of stem in rosette plants (b) Dwarfing of stem (c) Increase in flowering (d) Appearance of flowers. *(Chhatisgarh 2015)*

(10) The characteristics like expansion, breaking dormancy, promoting germination and flowering are associated with
(a) Auxins (b) Gibberellins (c) Cytokinins (d) Ethylene. *(AMU 2015)*

(11) The inhibitory effect of red light on flowering during critical dark period in short day plants can be overcome by
(a) blue light (b) far-red light (c) infra-red rays (d) ultraviolet rays. *(AMUT 2016)*

(12) Seedless fruits can be induced by
(a) ABA and IAA (b) ABA and Zeatin (c) IAA and GA_3 (d) Ethylene and ABA. *(WB 2016)*

(13) Fruit and leaf drop at early stages can be prevented by the application of (a) Cytokinins (b) Ethylene (c) Auxins (d) Gibberellic acid. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as–.
*(a) If both **A** and **R** are true and **R** is the correct explanation of **A***
*(b) If both **A** and **R** are ture and **R** is not the correct explanation of **A***
*(c) If **A** is true but **R** is false.*
*(d) If both **A** and **R** are false.*

1. **Assertion**. Increase in size or volume is apparent growth.
Reason. It is external manifestation of growth due to formation of new protoplasm.
(A) (B) (C) (D)

2. **Assertion.** The first phytohormone to be discovered was auxin.
Reason. Light reaction of coleoptile tip attracted the attention of Darwin in the last quarter of nineteenth century.
(A) (B) (C) (D)

3. **Assertion**. TIBA (2 ,3, 5- triiodobenzoic acid) functions as antiauxin.
Reason. It blocks transport of auxin.
(A) (B) (C) (D)

4. **Assertion.** 2, 4-D is auxin commonly used in tissue culture.
Reason. 2, 4-D is a weedicide.
(A) (B) (C) (D)

5. **Assertion.** Plants have hormones called phytohormones.
Reason. They increase the rate of reaction, accelerate growth and other related changes.
(A) (B) (C) (D)

6. **Assertion.** Phase of cell division is also known as formative phase.
Reason. In formative phase new cells are produced from pre-existing cells through meiosis.
(A) (B) (C) (D) *(AIIMS 2007)*

7. **Assertion.** Plant growth as a whole is indefinite.
Reason. Plants retain the capacity of continuous growth throughout their life.
(A) (B) (C) (D) *(AIIMS 2011)*

8. **Assertion.** On plotting the length of the root against time, a linear curve is obtained.
Reason. An elongating root exemplifies arithmetic growth.
(A) (B) (C) (D) *(AIIMS 2013)*

9. **Assertion.** Plant growth regulators are very important for plant growth and development.
Reason. Auxins do not induce flowering in gymnosperms.
(A) (B) (C) (D) *(AIIMS 2015)*

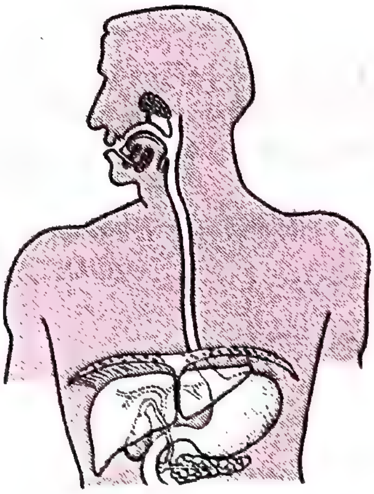
ANSWERS

Multiple Choice Questions

(1) —a (2) —c (3) —b (4) —a (5) —d (6) —a (7) —a (8) —b (9) —a (10) —b (11) —b (12) —c (13) —c

Assertion and Reason Type Questions

(1) —A (2) —B (3) —A (4) —B (5) —C (6) —C (7) —A (8) —A (9) —B



UNIT FIVE

HUMAN PHYSIOLOGY

Physiology is the study of function. **William Harvey** (1578–1657) is considered the *founder of modern physiology*. He is best known for demonstrating that blood circulates through the body. Another giant in the science of physiology was **Johannes Muller** (1801–1858). His main contribution to physiology was to make it a comparative science, emphasizing similarities and differences among species of animals. After Muller physiology grew in two directions— physical and chemical. The physicist-physiologists devised good methods for recording blood pressure, muscle contraction and nerve impulses. The chemist-physiologists studied chemical changes that take place in the body.

The central theme of this unit is human physiology. This unit will deal with the following topics :

(i) Digestion and absorption. (ii) Breathing and exchange of gases. (iii) Body fluids and their circulation. (iv) Excretory products and their elimination. (v) Locomotion and movement. (vi) Neural control and coordination and (vii) Chemical control and coordination.

For better understanding of the human physiology a brief account of human anatomy has also been given.

16 DIGESTION AND ABSORPTION

Nutrition, Food And Nutrients

The sum total of the processes by which the living organisms obtain those substances which are necessary for their growth and maintenance and for meeting their energy needs is called **nutrition.** What is taken in to supply the necessary nutritive elements, is called **food**. The chemical substances present in the food are called **nutrients.** In fact, nutrients provide raw materials for growth, repair of tissues, production of gametes, protection from diseases and metabolic energy for various body activities.

Types of Nutrients

Nutrients may be organic or inorganic in nature. The organic constituents of nutrients are carbohydrates, lipids, proteins and vitamins. The inorganic constituents of nutrients are minerals and water. Depending upon the quantity or functions, nutrients may be of the following types :

1. **Macronutrients.** These nutrients provide energy. Examples: carbohydrates, lipids and proteins.

2. **Micronutrients.** Although they do not provide energy yet their deficiencies cause specific diseases and abnormalities in animals including humans. Examples: minerals, vitamins and water.

Human Digestive System

Human digestive system consists of two main parts; alimentary canal and digestive glands.

(A) **Alimentary Canal.** It comprises the following parts :

1. **Mouth.** Human mouth consists of two parts.

(a) **Vestibule.** The vestibule is a slit-like space bounded externally by lips and cheeks and internally by the gums and teeth.

(b) **Oral* Cavity (Buccal Cavity).** It is inner portion of the mouth which has the following parts.

(i) **Palate.** The roof of the oral cavity (buccal cavity) is called palate. Anterior part of the palate is known as **hard palate** which bears transverse ridges, the **rugae.** The posterior part of the palate is smooth and is termed the **soft palate.** The hinder free part of the soft palate freely hangs down as a small flap, the **uvula.**

(ii) **Tongue.** The tongue is attached to the floor of the mouth by a fold called the **lingual frenulum.** An inverted V-shaped furrow termed the **sulcus terminalis** divides the

*Also called mouth cavity proper.

upper surface of the tongue into anterior **oral part** and posterior **pharyngeal part.** The apex of the sulcus terminalis projects backward and is marked by a small median pit, named the **foramen caecum.**

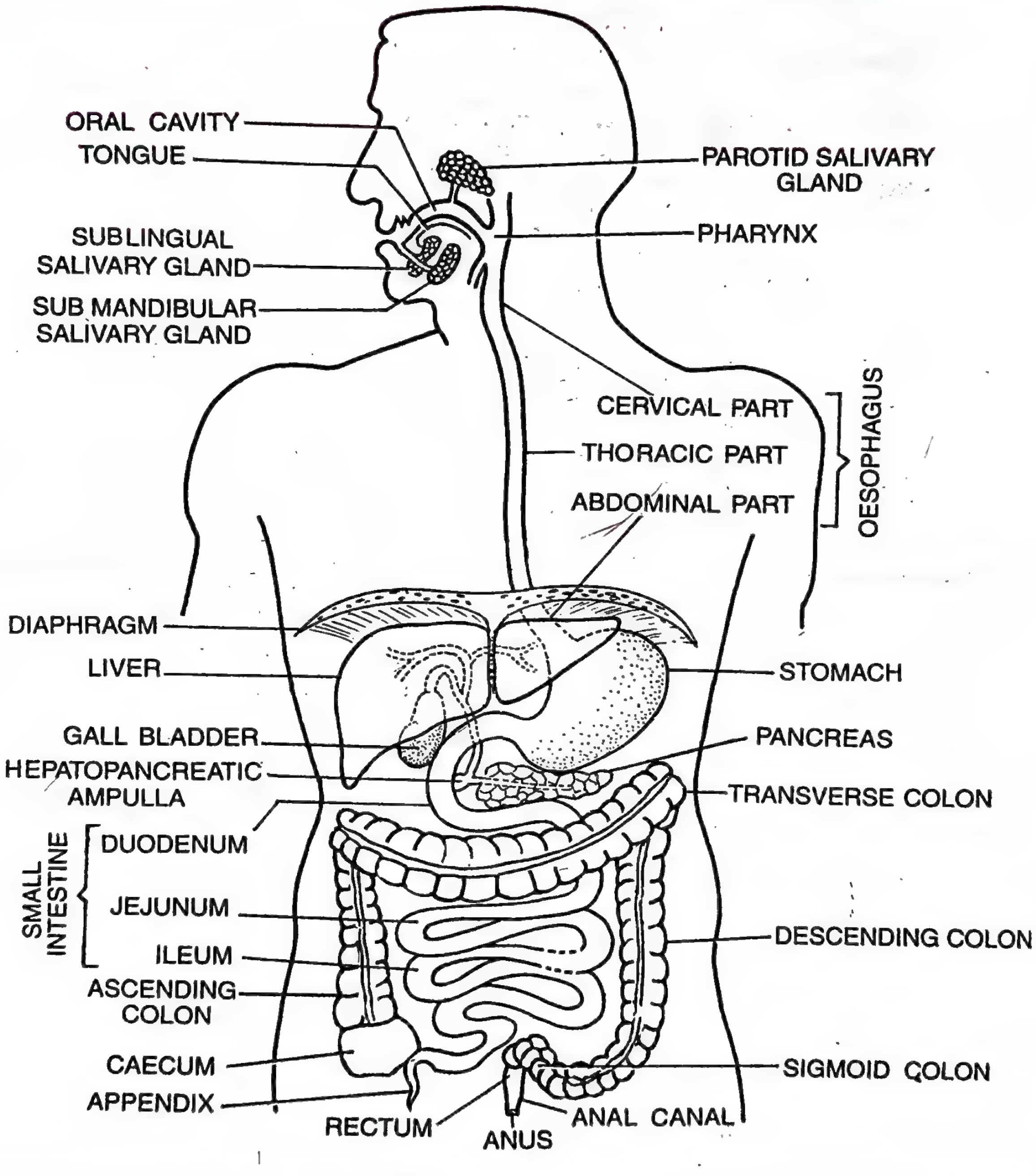


Fig. 16.1. Human digestive system.

Papillae. The upper surface of the tongue has four types of papillae (little projections).

(a) **Vallate papillae or Circumvallate papillae** are usually about 8 to 12 in number. Each vallate papilla contains upto 100 taste buds. These papillae are the *largest* of the four types of papillae.

(b) **Filiform papillae** are the *smallest* and *most numerous* of the four types. They are conical. They are found mainly near the centre and most of the upper surface of the tongue. These papillae contain *tactile* (touch) receptors but not taste buds.

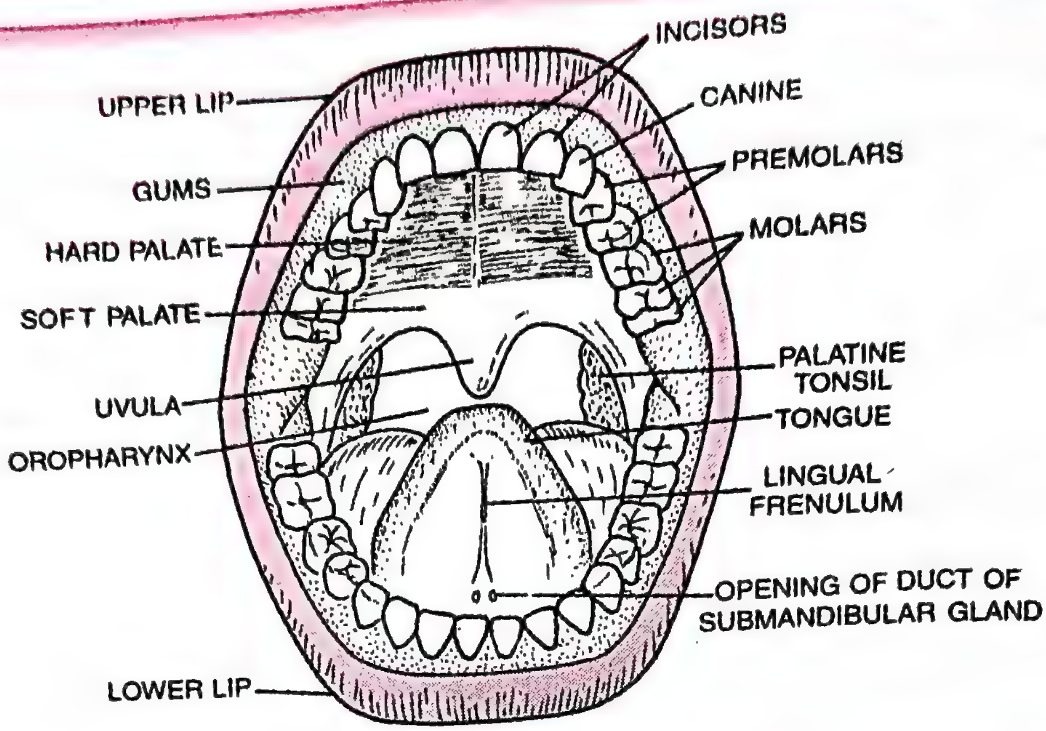


Fig. 16.2. Human oral cavity.

(c) **Fungiform papillae** are much less numerous than the filiform papillae. They are rounded but smaller than vallate but larger than filiform papillae. They are most numerous near the tip of the tongue. Each fungiform papilla contains about five taste buds.

(d) **Foliate papillae** are *not developed in human tongue*. These are leaf-like and are situated at the sides of the base of the tongue. On each border there are four or five vertical folds. Their taste buds degenerate in early childhood.

Human tongue has four **taste areas** (sweet, salt, sour and bitter). Areas of sweet and salt can overlap.

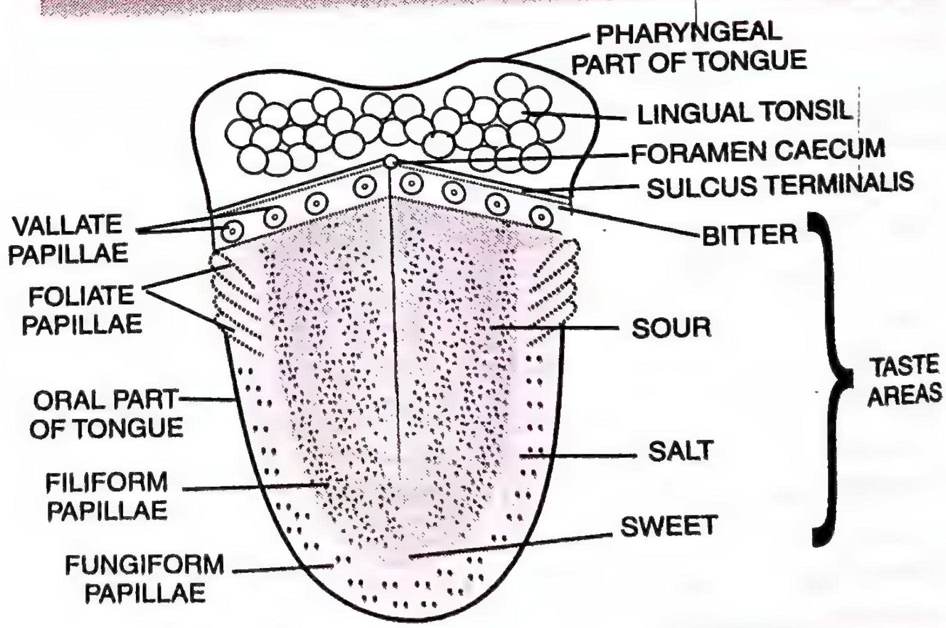


Fig. 16.3. Upper surface of human tongue.

Functions of the Tongue. The tongue acts as an accessory digestive organ. (i) It helps in chewing the food. (ii) It aids in swallowing the food. (iii) It acts as a brush to clean the teeth. (iv) It plays a role in speech. (v) It is an organ of taste.

Teeth. (a) **Characteristics**. Men have **diphyodont** (two sets of teeth— **milk** or **deciduous** and **permanent**), **thecodont** (teeth are embedded in the sockets of the jaw bones) and **heterodont teeth** (different types of teeth). There are present four kinds of teeth— incisors, canines, premolars and molars. **Incisors**. They are usually specialized for cutting. **Canines**. They lie immediately behind the incisors. They are also used for cutting the food.

Premolars and **molars.** These are called cheek teeth which are broad, strong crushing teeth. Third molars in human being are called **wisdom teeth.** The latter are vestigial in human beings.

(b) **Number.** The milk or deciduous or temporary teeth are 20 in number; 10 each in the upper jaw and in the lower jaw. The milk teeth begin to erupt when the child is about 6 months old and should all be present by the end of 24 months. The permanent teeth begin to replace the milk teeth in the 6th year of age. These teeth are 32 and usually complete by 18–25 years.

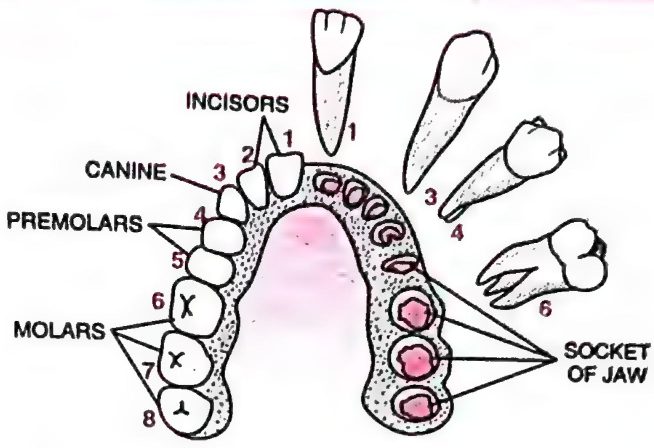


Fig. 16.4. Arrangement of different types of teeth in the jaws on one side and the sockets on the other side.

(c) **Dental Formulae.** Milk teeth of man include 8 incisors, 4 canines and 8 molars (premolars are absent). Molars of milk teeth are shed off and premolars of permanent teeth take their place. The permanent teeth are 8 incisors, 4 canines, 8 premolars and 12 molars. Thus 12 teeth (8 premolars and 4 molars) are **monophyodont** (teeth which grow only once in life). Dental Formulae of milk teeth and permanent teeth of human are given below.

$$\frac{212}{212} \times 2 = 20 \qquad\qquad \frac{2123}{2123} \times 2 = 32$$

Milk teeth		Permanent Teeth

The dental formula gives half of the total number of teeth. This is doubled to determine the full number.

(d) **Structure.** A typical tooth consists of three regions ; **crown**— the part which projects above the gums, the **neck**— the part which is surrounded by gum and the **root**— the part which is embedded in the bone. The incisors and canines have one root, the upper first premolars have two roots and the upper second premolars and lower premolars usually have only one root. The upper molars have three roots and the lower molars have two roots.

A human tooth consists of the following parts : **Enamel.** It is the *hardest substance of the human body.* It covers the dentin in the crown. **Dentin.** It has numerous fine canaliculi that pass radially from the pulp cavity towards the enamel. **Cement.** It covers the root of the tooth. **Periodontal Ligament.** It is made up of collagen fibres and covers the cement. It fixes the tooth in its socket. **Pulp Cavity.** Dentin encloses the pulp cavity that contains a mass of cells, blood vessels and nerves which constitute the **pulp.** Narrow extensions of the pulp cavity called **root canals,** run through the root of the tooth. Apart from the connective tissue cells of the pulp and of the **periodontal membrane** and the **cementocytes** in cement, there are two main types of cells. These are dentin forming **odontoblasts** and enamel forming **ameloblasts.**

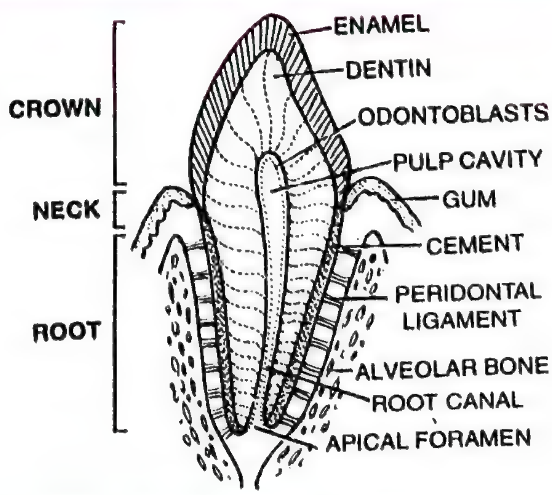


Fig. 16.5. Vertical section of human incisor.

2. **Pharynx (Throat).** It is divided for descriptive purposes into three parts ; the nasopharynx, oropharynx and laryngopharynx.

(i) The **nasopharynx** (nasal part of the pharynx) lies behind the nasal cavities, above the soft palate. The **Eustachian tube** (also called **auditory tube**) connects nasopharynx with the middle ear.

(ii) The **oropharynx** (oral part of the pharynx) lies behind the oral cavity (buccal cavity). The nasopharynx and oral cavity open into the oropharynx which is a common passage for both food and air.

(iii) The **laryngopharynx** (laryngeal part of the pharynx), is the most inferior portion of the pharynx. It leads into the oesophagus behind and into the larynx infront.

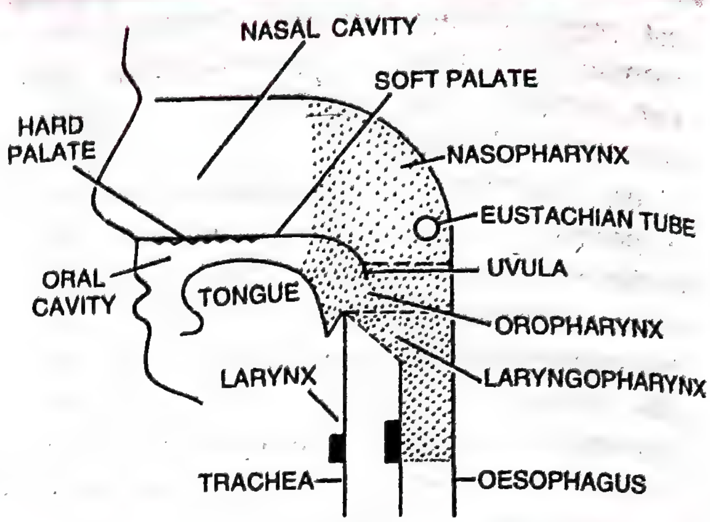


Fig. 16.6. Diagram showing three parts of pharynx.

Function. The pharynx is a common passage for food and air.

Waldeyer's Ring.

The lymphatic tissues of the pharynx and oral cavity are arranged in a ring like manner, which are collectively called Waldeyer's ring (= Waldeyer's lymphatic ring). The ring mainly consists of the following :

(i) **Pharyngeal Tonsil** is attached to pharynx. In children pharyngeal tonsil may become enlarged and is then referred to as the **adenoids.** The resulting swelling may be a cause of obstruction to normal breathing.

(ii) **Tubal Tonsils** are situated around the Eustachian tube.

(iii) **Palatine Tonsils** are attached to the palate. The palatine tonsils are often infected (**tonsillitis**) leading to sore throat. Such enlarged tonsils may become a focus of infection and their surgical removal (**tonsillectomy**) becomes necessary.

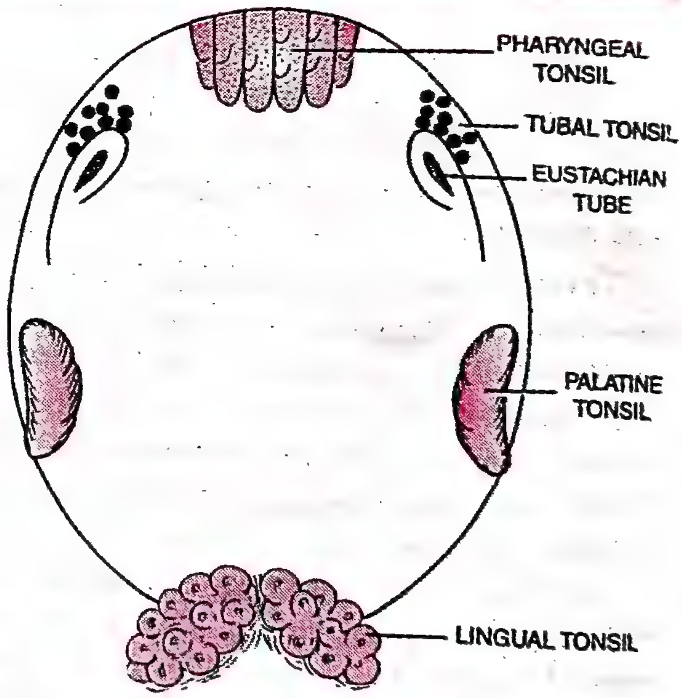


Fig. 16.7. Waldeyer's Ring.

(iv) **Lingual Tonsil** is attached to pharyngeal part of the tongue.

All these lymphoid tissues are active in production of immunoglobin–A which forms an important part of our immune system.

3. **Oesophagus.** The human oesophagus or **food pipe** is about 25 cm long. It lies behind the trachea and the heart. It comprises three parts : **cervical part** in the neck, **thoracic part** in the thorax and **abdominal part** in the abdomen. The oesophagus passes through the diaphragm and opens into the stomach.

Function. The oesophagus transfers food from the pharynx to the stomach.

4. **Stomach (= Gaster).** It is the widest organ of the alimentary canal. The stomach is J-shaped organ. The **lesser curvature** lies on the posterior surface of the stomach. The **greater curvature** is on the anterior surface of the stomach. The fold of peritoneum which attaches the stomach to the posterior abdominal wall extends beyond the greater curvature. This is called the **greater omentum** which stores fat. The stomach has four parts : cardiac part, fundus, body and pyloric part.

(i) **Cardiac Part (= cardia).** It is so called because it is present near the heart. The **gastroesophageal sphincter** (= cardiac sphincter) lies in the opening between oesophagus and stomach. *It is not a true valve. It is a functional sphincter.*

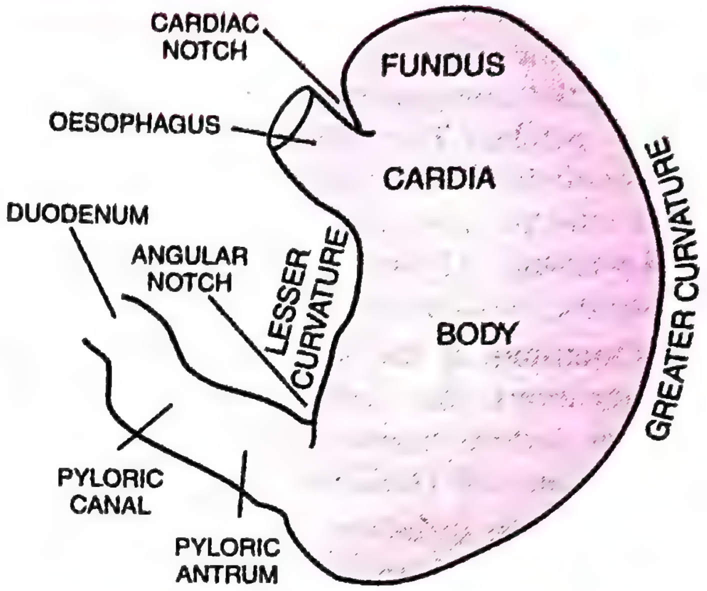


Fig. 16.8. Human Stomach.

(ii) **Fundus.** It is commonly filled with air or gas.

(iii) **Body.** It is the main part of the stomach.

(iv) **Pyloric Part (Pylorus).** It is the posterior part of the stomach.

The pyloric part is divided into the **pyloric antrum** and the **pyloric canal**. The latter opens into the duodenum. The **pyloric sphincter** guards the opening between the stomach and the duodenum and periodically permits partially digested food to leave the stomach and enter the duodenum.

Functions of the Stomach. It stores food for some time. It churns and breaks up food and mixes the pieces with gastric juice. Partial digestion of food (proteins and fats) takes place here. It produces ***Castle's intrinsic gastric factor** (a glycoprotein) which is necessary for the absorption of vitamin B_{12} to be absorbed in the intestine. It secretes proenzymes— pepsinogen and prorennin and enzymes gastric lipase and gastric amylase. It also secretes **gastrin** (hormone). Alcohol, aspirin, some lipid-soluble drugs, moderate amounts of sugar and water are absorbed by the stomach wall.

5. **Small Intestine.** It is so named because it has small diameter. Length is correlated with the height of the individual but not with weight. It is the longest part of the alimentary canal. It is about 6.25 metres long. It comprises three parts; duodenum, jejunum and ileum.

(i) **Duodenum.** It is so called because it is about as long as the breadth of 12 fingers. It is about 25 cm long and is the shortest, widest part of the small intestine. It is somewhat C-shaped. The **hepatopancreatic ampulla (ampulla of Vater)** opens into the duodenum. This ampulla receives both bile duct from the liver and main pancreatic duct from the pancreas (Fig. 16.12). Iron is mainly absorbed in the duodenum.

(ii) **Jejunum.** It has a diameter of about 4 cm. Its wall is thick. It is redder and more vascular. It is the middle part of the small intestine and is about 2.5 metres long.

(iii) **Ileum.** It has a diameter of 3.5 cm. Its wall is thinner than that of the jejunum. It is the longest part of small intestine and is about 3.5 metres long.

Both the jejunum and ileum are greatly coiled. They are suspended by **mesentery**.

Small nodules of lymphatic tissue can be seen along the entire length of the small

*William B. Castle, a U.S. Physician.

intestine. In some places, particularly along the ileum, these nodules are clustered together in groups called **Peyer's patches** or **lymph nodules**. Peyer's patches are a distinguishing characteristic of the ileum, which produce lymphocytes (type of WBCs). Finger-like projections of the mucosa, the **villi** are present in the small intestine. Villi are absent over the Peyer's patches. The villi increase the surface of the small intestine. Each villus is covered with epithelium and contains a lymph capillary **(lacteal)** and blood capillaries. The entire small intestine has circular folds of the mucous membrane, the **plicae circulares ('Valves' of Kerkring)**. These folds are more prominent in the jejunum. They further increase the absorptive surface considerably.

Functions of the small intestine. The small intestine completes digestion of proteins, carbohydrates, fats and nucleic acids. It absorbs nutrients into the blood and lymph. It secretes certain hormones such as cholecystokinin, secretin, enterogastrone, duocrinin, enterocrinin and villikinin. It also secretes digestive enzymes.

6. **Large Intestine**. Its diameter is larger than that of the small intestine. Hence it is so named. It is about 1.5 metres long and is divisible into three parts ; caecum, colon and rectum.

(i) **Caecum and vermiform appendix**. The caecum is a pouch-like structure which is about 6 centimetres. The **vermiform appendix** (commonly called the appendix) is an outgrowth of the caecum. It is a slightly coiled blind tube of about 8 centimetres long. Its wall contains prominent lymphoid tissue. Appendix is thought to be vestigial. The inflammation of vermiform appendix is called **appendicitis**. The caecum and appendix are well developed in herbivorous mammals like rabbits.

(ii) **Colon**. The caecum leads into the colon, which is divided into four regions; the **ascending, transverse, descending** and **sigmoid colon (pelvic colon** is its former name). *Ascending colon is the shortest part of the colon.* The colon has three longitudinal bands called **taeniae coli** and small pouches called **haustra** (sing. haustrum).

(iii) **Rectum**. The sigmoid colon opens into the rectum. The rectum comprises the last 20 centimetres of the digestive tract and terminates in the 2-centimetre long **anal canal.**

The opening of the anal canal is called **anus.** The anus has an **internal anal sphincter** composed of smooth muscle fibres and an **external anal sphincter** comprised of striped (voluntary) muscle fibres.

Structures formed due to enlargements of veins of anal columns in anal canal as well as anus are called **haemorrhoids** or **piles.**

Functions of the large intestine. The chief functions of the large intestine are the absorption of water and the elimination of solid wastes. However, moderate quanitities of vitamin K and vitamin B complex are manufactured by bacteria in the large intestine.

Histology of Human Gut (Alimentary Canal)

The wall of alimentary canal consists of four basic layers. From the outer surface inward to the lumen (cavity) the layers are as follows :

1. **Visceral peritoneum (= Serosa).** It is made up of squamous epithelium and areolar connective tissue. It is continuous with the **mesentery.** Since the oesophagus lies outside the coelom, its outer wall is not covered by peritoneum (serosa) but by an irregular coat of dense elastic fibrous connective tissue called **adventitia externa** (= external adventitia).

2. **Muscularis (Muscular coat)**. It is composed of outer **longitudinal** and inner **circular muscle fibres**. In the stomach an additional layer of **oblique muscle layer** is found inner to the circular muscle fibres. These muscle fibres are unstriped (smooth). In between

the longitudinal and circular muscle fibres there is a network of nerve cells and parasympathetic nerve fibres, called the **Auerbach's plexus (= myenteric plexus)**. The Auerback's plexus controls peristalsis.

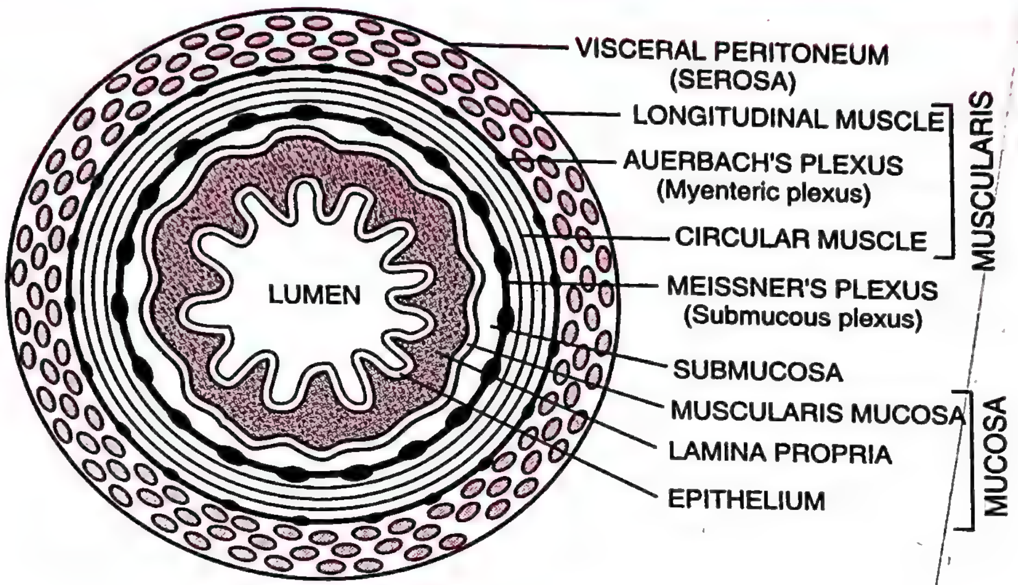


Fig. 16.9. Diagrammatic representation of transverse section of gut (alimentary canal).

3. **Submucosa.** It consists of loose connective tissue richly supplied with blood and lymphatic vessels and in some areas with glands. Another network of nerve cells and sympathetic nerve fibres, called **Meissner's plexus** (= submucosal plexus) is present between the muscular coat and the mucosa. This plexus controls the secretion of intestinal juice.

4. **Mucosa** (= Mucous membrane). It is the innermost layer lining the lumen of the alimentary canal. It is so named because it secretes mucus to lubricate the inner lining of the gut. This layer forms irregular folds (**rugae**) in the stomach. Mucosa is composed of three layers :

(i) The **muscularis mucosa** consists of outer longitudinal and inner circular muscle fibres, both are unstriped.

(ii) The **lamina propria** consists of loose connective tissue, blood vessels, glands and some lymphoid tissue.

(iii) The **epithelium** forms gastric glands in stomach, and villi and intestinal glands in small intestine.

In upper one third of the oesophagus both Auerbach and Meissner's plexuses are absent.

(B) Digestive Glands

1. Salivary Glands (Fig. 16.10)

Salivary glands discharge their secretion into the oral cavity. In man, the salivary glands are three pairs— parotid, sublingual and submandibulor glands. (i) **Parotid glands**. These are

the **largest** salivary glands which are situated near the ears. Their ducts open into the oral cavity near the upper second molars. The duct of parotid gland is called **Stenson's duct.** (ii) **Sublingual glands.** These are smallest salivary glands which are located beneath the tongue and their ducts called **sublingual ducts** or **ducts of Rivinus** which open into the floor of the oral cavity. (iii) **Submandibular** (also called **submaxillary) glands.** These are medium sized salivary glands which are located at the angles of the lower jaw. Their ducts open into the oral cavity near the lower central incisors. The duct of submandibular gland is called **Wharton's duct.** The parotid salivary glands secrete much of **salivary amylase** or **α–amylase (= ptyalin).** Sub-lingual and sub-mandibular salivary glands secrete salivary amylase and mucus. Salivary amylase is absent in herbivores.

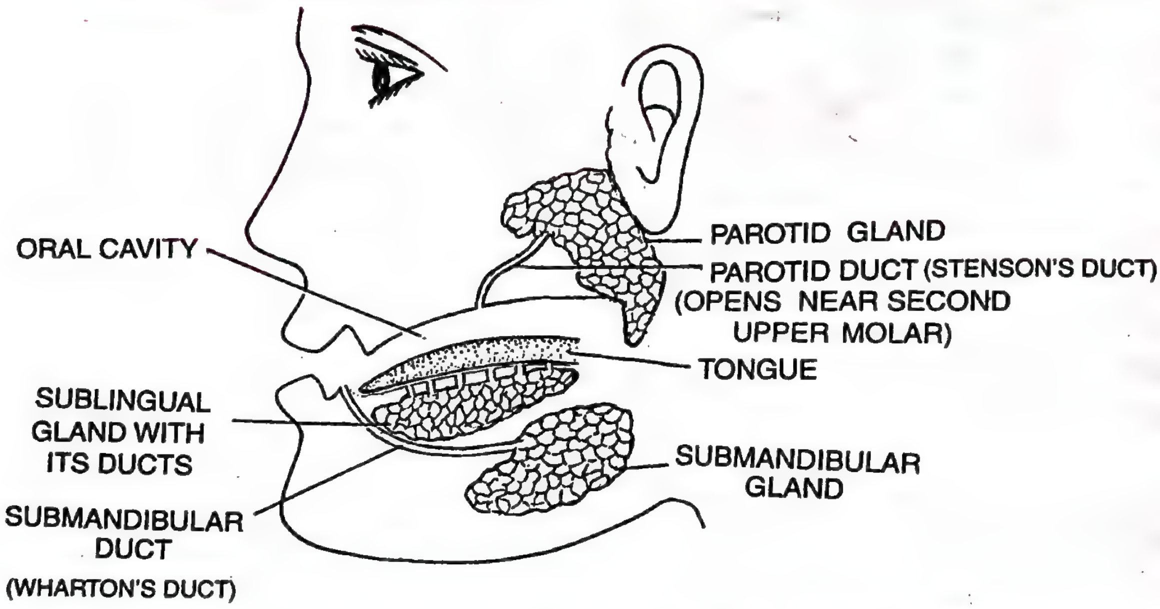


Fig. 16.10. Human Salivary Glands.

The disease **mumps** is a viral infection that may involve one or both parotid salivary glands.

The fluids secreted by the salivary glands constitute **saliva.** Saliva is slightly acidic (*p*H 6.8). About 1,000–1500 ml of saliva is secreted per day. Saliva is a mixture of water and electrolytes (Na^+, K^+, Cl^-, HCO_3^-), derived from blood plasma, mucus and serous fluids (watery constituent of saliva), and salivary amylase or ptyalin (enzyme) and **lysozyme** (antibacterial agent). Ions of **thyocyanate** are also present in the saliva.

2. **Gastric Glands** (Fig. 16.11)

These are numerous microscopic, tubular glands formed by the epithelium of the stomach. Gastric glands have three major types of cells.

(i) **Chief cells or Peptic cells (= Zymogenic cells)** are usually basal in location and secrete gastric digestive enzymes as proenzymes* or zymogens; **pepsinogen** and **prorennin.** The chief cells also produce small amount of **gastric amylase** and **gastric lipase.** Gastric amylase action is inhibited by the highly acid condition. Gastric lipase contributes little to digestion of fat. Prorennin is secreted in young mammals. It is not secreted in adult mammals.

*Proenzymes — inactive forms of enzymes.

(ii) **Oxyntic cells (= Parietal cells)** are large and are most numerous on the side walls of the gastric glands. They are called oxyntic cells because they stain strongly with eosin. They are called parietal cells as they lie against the basement membrane. They secrete hydrochloric acid and **Castle's intrinsic gastric factor** that helps in the absorption of vitamin B_{12} in the ileum.

(iii) **Mucous cells (= Goblet cells)** are present throughout the epithelium and secrete mucus.

The secretions of these cells form **gastric juice** with *p*H 1.5–2.5 (very acidic). Infant's gastric juice *p*H is 5.0. About 2,000–3,000 ml of gastric juice is secreted per day. The gastric juice contains two proenzymes— **pepsinogen** (propepsin) and **prorennin,** and enzymes **gastric lipase** and **gastric amylase**, and mucus and hydrochloric acid.

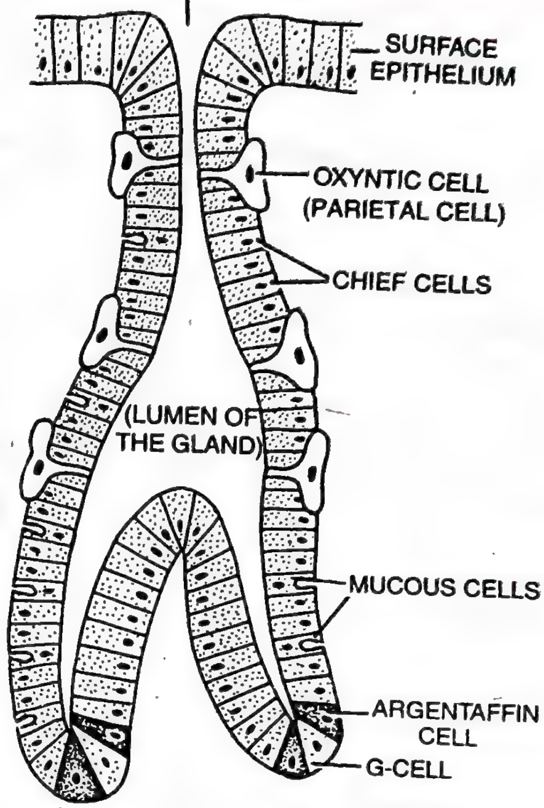


Fig. 16.11. Diagram showing gastric gland.

The epithelium of gastric glands also has the following two types of cells :

(i) **Endocrine cells** are usually present in the basal parts of the gastric glands. These are argentaffin cells and Gastrin cells (= G-cells). **Argentaffin* cells** produce **serotonin** (its precursor is 5-hydroxytryptamine, 5-HT), **somatostatin** and **histamine. Gastrin Cells** (= G-cells) are present in the pyloric region and secrete and store the hormone **gastrin**. Serotonin is a vasoconstrictor and stimulates the smooth muscles. Somatostatin suppresses the release of hormones from the digestive tract. Histamine dilates the walls of blood vessels. Gastrin stimulates the gastric glands to release the gastric juice.

(ii) **Stem cells** are undifferentiated cells that are also present in the epithelium of the gastric glands. They multiply and replace other cells. They increase in number when the gastric epithelium is damaged (*e.g.,* when there is a gastric ulcer) and play an important role in healing.

3. **Liver (= Hepar).**

It is the **largest gland** of the body. The liver lies in the upper right side of the abdominal cavity just below the diaphragm. It is heavier in males than females. In males it generally weighs 1.4–1.8 Kg and in females 1.2–1.5 Kg.

The liver is divided into two main lobes— **right** and **left lobes** separated by the **falciform ligament**. The latter is a membrane that is continuous with the peritoneum. The right lobe of the liver is futher differentiated into **right lobe proper,** a **quadrate lobe** and a **caudate lobe** on the posterior surface. Internally, the structural and functional units of liver are the **hepatic lobules** containing **hepatic cells** arranged in the form of cords. Each lobule is covered by a thin connective tissue sheath called the **Glisson's capsule.** *Glisson's capsule is the characteristic feature of mammalian liver.* The mammalian liver also contains **Kupffer cells** that are phagocytic cells and eat worn out WBCs, RBCs and bacteria.

*L. *argentum* = silver + *affinitas* = affinity — pertaining to cells or tissue elements that reduce silver ions in solution, thereby becoming stained brown or black.

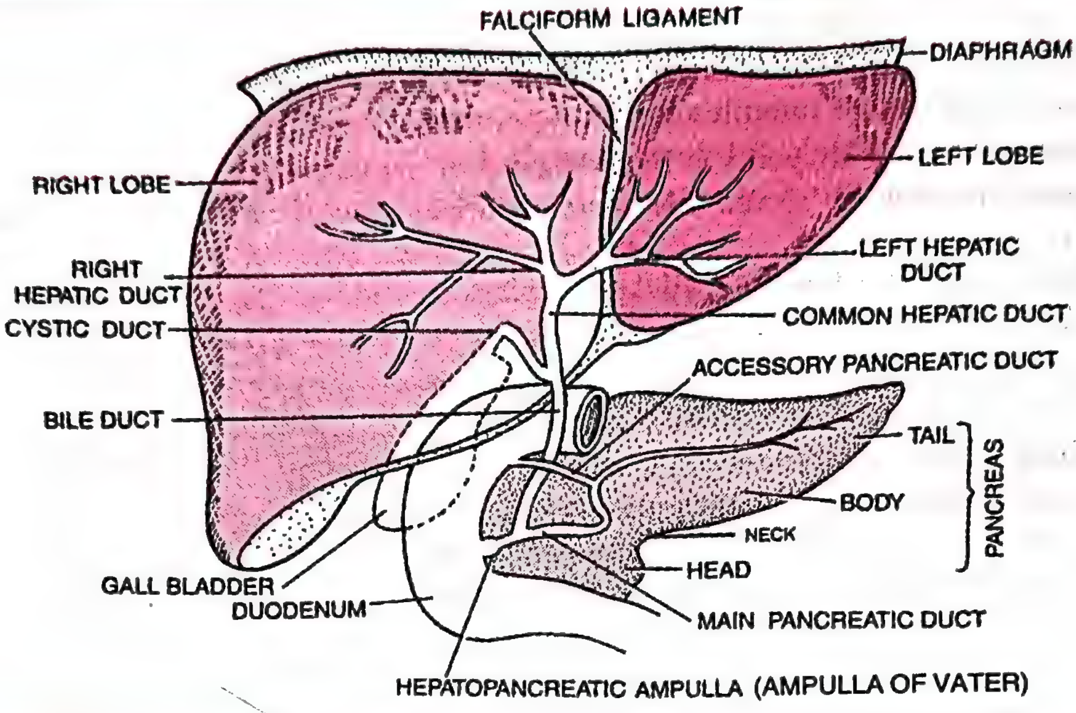


Fig. 16. 12. Liver and pancreas with associated structures.

Fat storage cells are also present. The plates of liver cells are separated from the endothelial lining of the sinusoid by a narrow **perisinusoidal space of Disse.** Some fat cells may also be seen in the space of Disse.

Blood vessels and bile ductules present in the portal canals are surrounded by a narrow **space of Mall.**

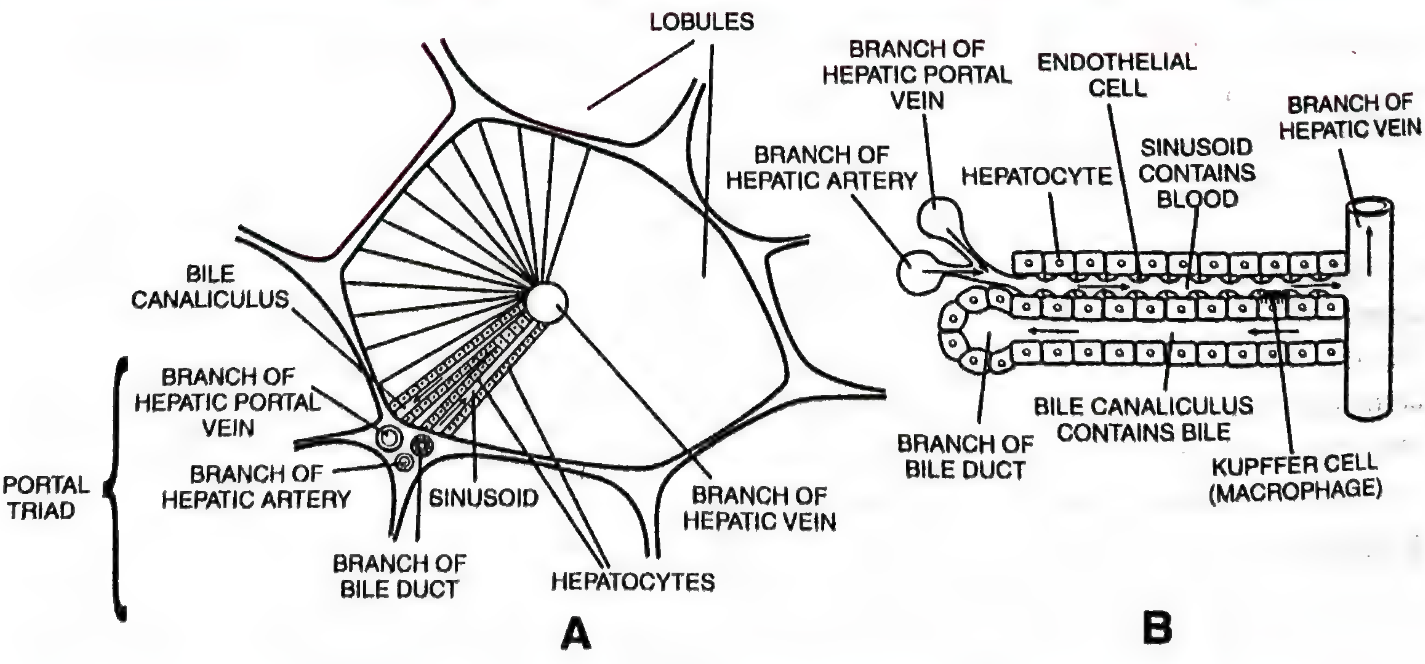


Fig. 16.13. A, Diagram of a Transverse section of a liver lobule (Arrows indicate flow of blood in sinusoid and the flow of bile in canalculi). B, A simplified diagram of part of a liver lobule.

Bile is secreted by the liver cells (hepatocytes). Bile enters **bile canaliculi** or bile capillaries (a net work of tubular spaces between the liver cells). The bile canaliculi empty into small **Hering's canals** walled by cuboidal epithelium. These canals pour bile into interlobular bile duct (=bile ductule) walled by columnar epithelium.

Gall Bladder. A pear shaped sac like structure is attached to the posterior surface of the liver by connective tissue. It stores bile secreted by the liver. Rat and horse do not have gall bladder.

Ducts. The **right** and **left hepatic ducts** join to form the **common hepatic duct.** The latter joins the **cystic duct** which arises from the gall bladder. The cystic duct and common hepatic duct join to form **bile duct** which passes downwards posteriorly to join the main **pancreatic duct** to form the **hepatopancreatic ampulla** (= **ampulla of Vater**). The ampulla opens into the duodenum. The opening is guarded by the **sphincter** of **Oddi.** The **sphincter of Boyden** surrounds the opening of the bile duct before it is joined with the pancreatic duct.

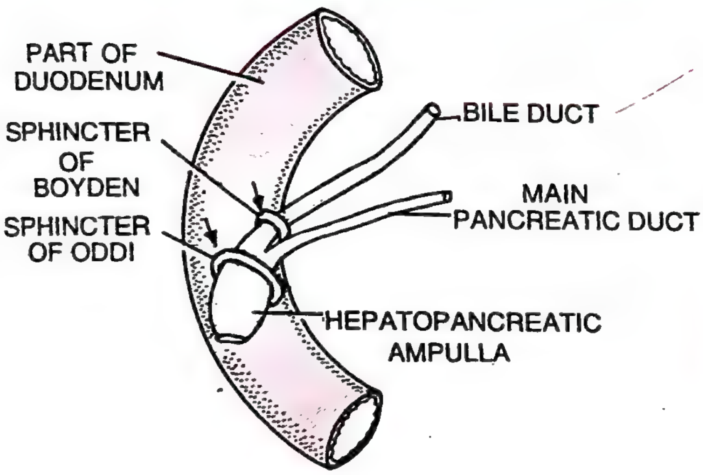


Fig. 16.14. Diagram showing sphincter of Boyden and sphincter of Oddi.

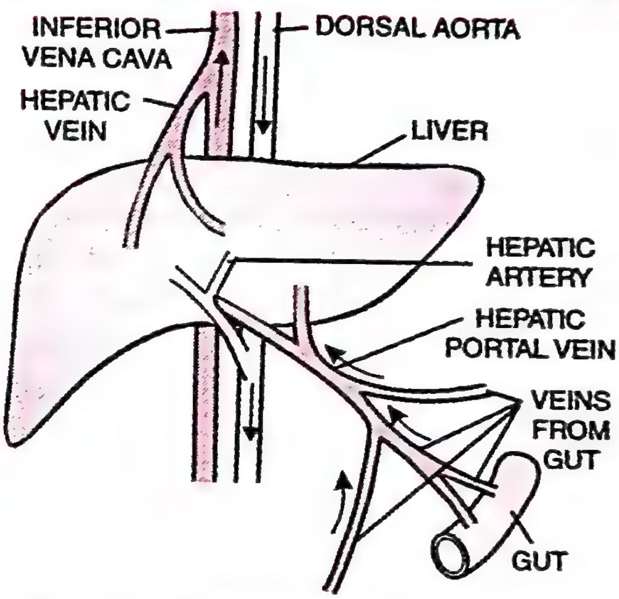


Fig. 16.15. Diagram showing the blood supply to liver from two sources.

Blood Supply (Fig. 16.15). Blood enters the liver from *two sources*. From the hepatic artery it gets oxygenated blood and from the hepatic portal vein it receives deoxygenated blood. Blood in the hepatic artery comes from the aorta. Blood in the hepatic portal vein comes directly from the intestine containing newly absorbed nutrients. The hepatic portal vein also brings blood from the spleen to the liver.

Liver has high power of regeneration.

Functions of liver

1. **Production of Bile.** The liver secretes **bile** (hepatic bile *p*H 8.6). The bile is stored in the gall bladder (gall bladder bile *p*H 7.6). About 500 – 1,000 ml of bile is secreted by liver in a day. Bile salts (**sodium bicarbonate, sodium glycocholate, sodium taurocholate**) help in the digestion of fats in the small intestine by bringing about their **emulsification** (conversion of large fat droplets into small ones). Usual flow of bile from the liver is → hepatic ducts → gall bladder → cystic duct → bile duct → hepatopancreatic ampulla → duodenum.

2. **Deamination.** It is a process by which the amino group (—NH_2) is removed from the amino acids resulting in the production of ammonia which is converted into urea.

3. **Excretion.** (i) Liver synthesizes urea with the help of ammonia and carbon dioxide. Urea is passed out through excretory system. (ii) The bile contains bile pigments (**bilirubin**— yellow and **biliverdin**— green) that are also excretory products. (iii) The liver cells also eliminate certain other waste products like cholesterol, metal ions and waste-products of haemoglobin. These waste-products and bile pigments reach the duodenum through bile and pass out with faeces.

4. **Glycogenesis.** It is the conversion of the excess of glucose into glycogen by liver cells with the help of insulin secreted by the pancreas.

5. **Glycogenolysis.** It is the conversion of glycogen into glucose by the liver cells with the help of glucagon secreted by the pancreas.

6. **Lipogenesis.** It is the conversion of excess of glucose and amino acids into fats.

7. **Gluconeogenesis.** It is the formation of glucose or glycogen from non-carbohydrate sources such as amino acids, fatty acids, glycerol, etc. It also occurs in the kidneys and striped muscles.

8. **Detoxification.** Liver converts toxic substances into harmless substances, *e.g.*, harmful **prussic acid**, formed during metabolism in all body cells, is neutralized and rendered harmless by liver cells.

9. **Haemopoiesis.** The process of formation of blood corpuscles is called haemopoiesis. The liver produces red blood corpuscles in the embryo.

10. **Synthesis of Blood Proteins.** The liver produces blood proteins such as prothrombin and fibrinogen that help in the clotting of blood.

11. **Secretion of Heparin.** Liver secretes heparin (anticoagulant).

12. **Lymph Formation.** Liver is an important seat of lymph formation.

13. **Synthesis of Vitamin A.** Liver synthesizes vitamin A from b-carotene. The latter is an orange-yellow substance of carrot.

14. **Secretion of Enzymes.** Liver secretes certain enzymes which play important roles in the metabolism of proteins, fats and carbohydrates in the body.

15. **Destruction of Red Blood Corpuscles.** The old worn out red blood corpuscles are broken down in the liver cells. Their haemoglobin is changed into bile pigments.

16. **Phagocytosis.** The **Kupffer's cells** of the liver engulf the disease causing microorganisms, dead cells and foreign matter.

17. **Osmoregulation.** Liver produces **angiotensinogen** (a protein) which helps kidneys in maintaining body fluid osmoregulation.

18. **Production of Heat.** Due to high metabolic activities of the liver, enough heat is generated, which is essential for maintaining the optimum body temperature.

19. **Storage.** Liver stores (i) glycogen, (ii) Fats, (iii) Vitamins like A,D,E,K and B_{12}, (iv) Bile in the gall bladder, (v) Blood (vi) water, (vii) Iron, copper and potassium.

Functions of Bile

Bile is a watery greenish fluid mixture containing bile pigments, bile salts, cholesterol and phospholipids. Bile serves the following functions :

(i) **Neutralization of HCl.** Its sodium bicarbonate neutralizes HCl of chyme (semi-fluid food that comes from the stomach).

(ii) **Emulsification.** Sodium glycocholate and sodium taurocholate break the large fat droplets into the smaller ones. This process is called emulsification.

(iii) **Absorption of fat and fat-soluble vitamins.** Its salts help in the absorption of fat (fatty acids and glycerol) and fat-soluble vitamins (A, D, E and K) in the small intestine.

(iv) **Excretion.** Bile pigments (bilirubin and biliverdin) are excretory products.

(v) **Prevention of Decomposition.** Bile is alkaline hence it prevents the decomposition of food by preventing the growth of bacteria on it.

(vi) **Stimulation of Peristalsis.** Bile increases peristalsis of the intestine.

(vii) **Activation of Lipase.** *Bile contains no enzyme* but activates the enzyme lipase.

Obstruction of the hepatic or bile duct by gall stones or due to other causes is common. Jaundice occurring as a result of such obstruction is called **obstructive jaundice. In this** disease the bile is absorbed into the blood instead of going to the duodenum and cause yellowing of eyes and skin.

4. **Pancreas** (Fig. 16.12 & 16.16)

The pancreas is soft, lobulated, greyish- pink gland which weighs about 60 grams. It is about 2.5 centimetres wide and 12 to 15 centimetres long, located posterior to the stomach in the abdominal cavity.

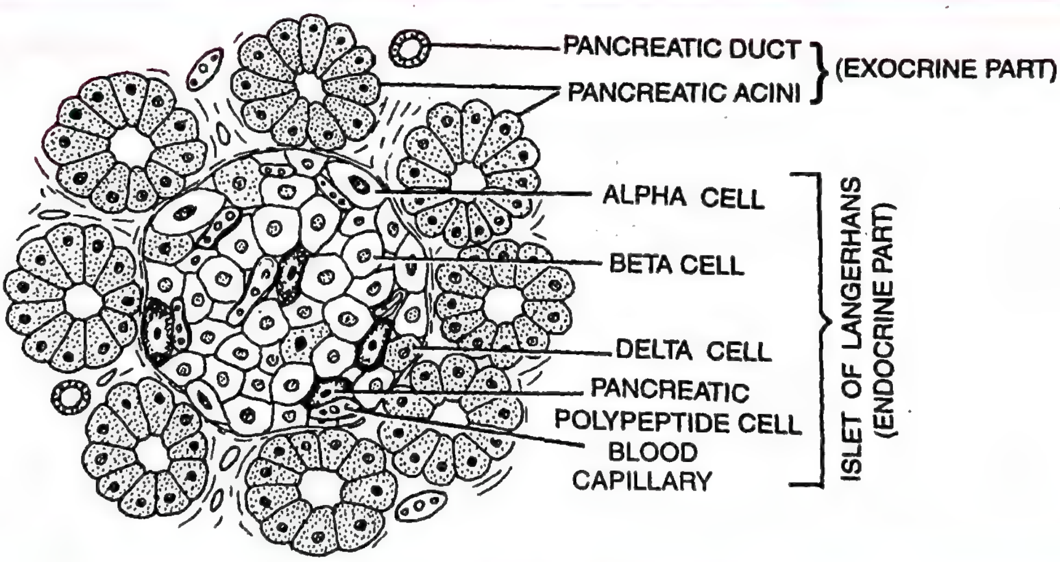


Fig. 16.16. Section of Pancreas.

External Structure of Pancreas. The Pancreas comprises the **head, neck, body** and **tail**. The head lies in the curve of the duodenum, the neck follows the head, the body behind the stomach and the tail reaches the spleen lying in front of the left kidney. The **main pancreatic duct (= duct of Wirsung)** is formed from smaller ducts within the pancreas. The main pancreatic duct opens into the hepatopancreatic ampulla (= **ampulla of Vater**). An **accessory pancreatic duct (= duct of Santorini)** is also present in the pancreas and opens directly into the duodenum.

Internal Structure of Pancreas. It consists of two parts : exocrine part and endocrine part.

(i) **Exocrine part.** The exocrine part of the pancreas consists of rounded **lobules (acini)** that secrete an alkaline **pancreatic juice** with *p*H 8.4. About 500–800 ml of pancreatic juice is secreted per day. The pancreatic juice is carried by the main pancreatic duct into

the duodenum through the **hepatopancreatic ampulla**. The accessory pancreatic duct directly pours the pancreatic juice into the duodenum. The pancreatic juice contains sodium bicarbonate, three proenzymes ; **trypsinogen, chymotrypsinogen** and **procarboxypeptidase** and some enzymes such as **elastase, pancreatic α-amylase, DNase, RNase** and **pancreatic lipase**. The pancreatic juice helps in the digestion of starch, proteins, fats and nucleic acids.

(ii) **Endocrine part.** The endocrine part of the pancreas consists of groups of **islets of Langerhans**. The human pancreas has about one million islets. *They are most numerous in the tail of the pancreas.* Each islet of Langerhans consists of the following types of cells which secrete hormones to be passed into the circulating blood.

(a) **Alpha cells** (= α-cells). These cells are more numerous towards the periphery of the islet and constitute 15%* of the islet of Langerhans. They produce **glucagon** hormone which converts glycogen into glucose in the liver. Thus glucagon is **diabetogenic hormone.**

(b) **Beta cells** (= β-cells). These cells are more numerous towards the middle of the islet and constitute 65%* of the islet of Langerhans. They produce **insulin** hormone which converts glucose into glycogen in the liver and muscles. Deficiency of insulin causes **diabetes mellitus.**

(c) **Delta cells** (= δ-cells). These cells are also found towards the periphery of the islet of Langerhans and constitute 5%* of the islet of Langerhans. They secrete **somatostatin (SS)** hormone which inhibits the secretion of glucagon by alpha cells and secretion of insulin by beta cells. This hormone also slows absorption of nutrients from the gastrointestinal tract.

Somatostatin secreted by argentaffin cells of gastric and intestinal glands suppresses the release of hormones from the digestive tract.

Somatostatin is also secreted by the hypothalamus of the brain where it inhibits the release of growth hormone (somatotropin) by the anterior lobe of pituitary gland. That is why it is also called growth inhibitory hormone.

(d) **Pancreatic polypeptide cells** (= PP cells or F-cells). Apart from the three main types of cells described above, the PP cells are also present in the pancreas, which constitute 15%* of the Islet of Langerhans. These cells secrete **pancreatic polypeptide** (PP) which inhibits the release of pancreatic juice.

Thus the pancreas performs two main functions *i.e.*, secretion of pancreatic juice which contains digestive enzymes and production of hormones.

5. **Intestinal Glands** (Fig. 16.17).

These are formed by the surface epithelium of the small intestine. These are of two types: **crypts of Lieberkuhn** and **Brunner's glands.**

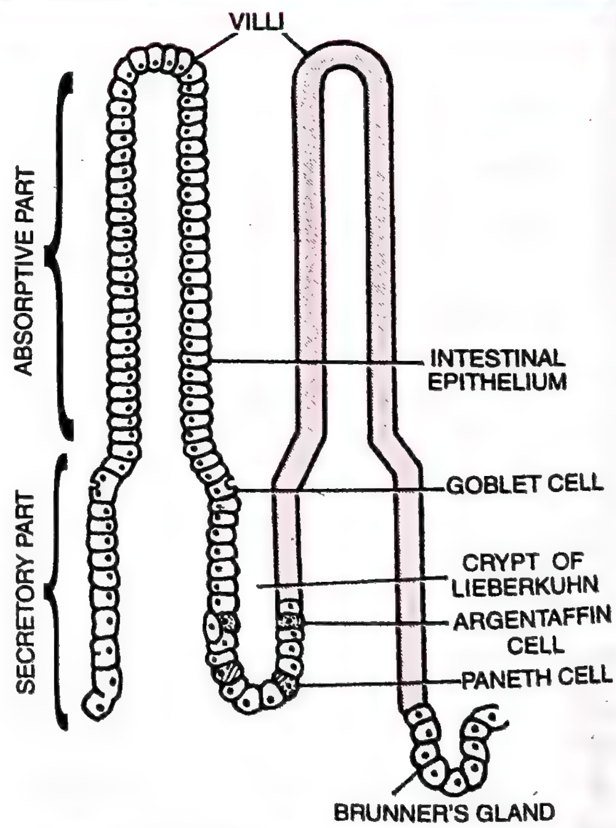


Fig. 16.17. Diagram showing intestinal glands (secretory Part) and villi (Absorptive Part)

* Percentage of the cells in the Islets of Langerhans is according to the Text Book of Surgery (16th Edition) by Sabiston.

(i) The **crypts of Lieberkuhn** are simple, tubular structures which occur throughout the small intestine between the villi. They secrete digestive enzymes and mucus. The mucus is secreted by the **goblet cells** (= mucous cells) whereas water and electrolytes are secreted by **enterocytes** present on the intestinal crypts. These crypts have at the base paneth cells and argentaffin cells.

(a) **Paneth cells** are found particularly in the duodenum. These cells are present in the bottom of crypts of Lieberkuhn. These cells are rich in zinc and contain acidophilic granules. The function of these cells is not certain but there is evidence that they secrete lysozyme (antibacterial substance). Paneth cells are also capable of phagocytosis.

(b) **Argentaffin cells** synthesize secretin hormone and 5-hydroxytryptamine (5–HT).

(ii) The **Brunner's glands** are *found only in the duodenum* and are located in the submucosa. They secrete a little enzyme and mucus. The mucus protects the duodenal wall from getting digested. Digestion of most of nutrients takes place in the duodenum under the action of various enzymes. The Brunner's glands open into the crypts of Lieberkuhn.

The secretion of intestinal glands is called **intestinal juice** or **succus entericus** with *p*H 7.8. About 2,000–3,000 ml of intestinal juice is secreted per day. The intestinal juice contains many enzymes— maltase, isomaltase, sucrase, lactase, α- dextrinase, enterokinase, aminopeptidases, dipeptidases, nucleotidases, nucleosidases and intestinal lipase.

In addition to the glands mentioned above the entire alimentary canal has **mucous glands** that produce mucus. The mucus lubricates the digestive tract and food.

Human digestive system has many accessory organs. Tongue, salivary glands, liver, gall bladder and pancreas are some important human **accessory digestive organs**.

Swallowing or Deglutition (Fig. 16.18)

The food is tasted in the oral cavity and mixed with saliva. Tongue manipulates food during chewing and mixing with saliva. This collection of food, the **bolus** (mass of food) is then pushed inward through the pharynx into the oesophagus. This process is called **swallowing** or **deglutition.** Swallowing involves co-ordinated activity of tongue, soft palate, pharynx and oesophagus. Swallowing is conveniently divided into three stages :

(i) **The Voluntary stage.** The tongue blocks the mouth. The bolus is forced to move from the oral cavity into the pharynx (oropharynx). This represents the **voluntary stage** of swallowing.

(ii) **The Pharyngeal stage** With the passage of the bolus into the pharynx, the involuntary **pharyngeal stage** of swallowing begins. The palate closes off the nose and the epiglottis seals off the glottis of larynx. Thus breathing is temporarily interrupted. The bolus is passed from the pharynx into the oesophagus.

(iii) **The Oesophageal stage.** This also represents the involuntary stage of swallowing. The bolus passes through the laryngopharynx and enters the oesophagus in 1 to 2 seconds. The respiratory passage then reopens and breathing resumes.

Swallowing is controlled by a **swallowing centre** located in the medulla oblongata and lower pons varolii of the brain.

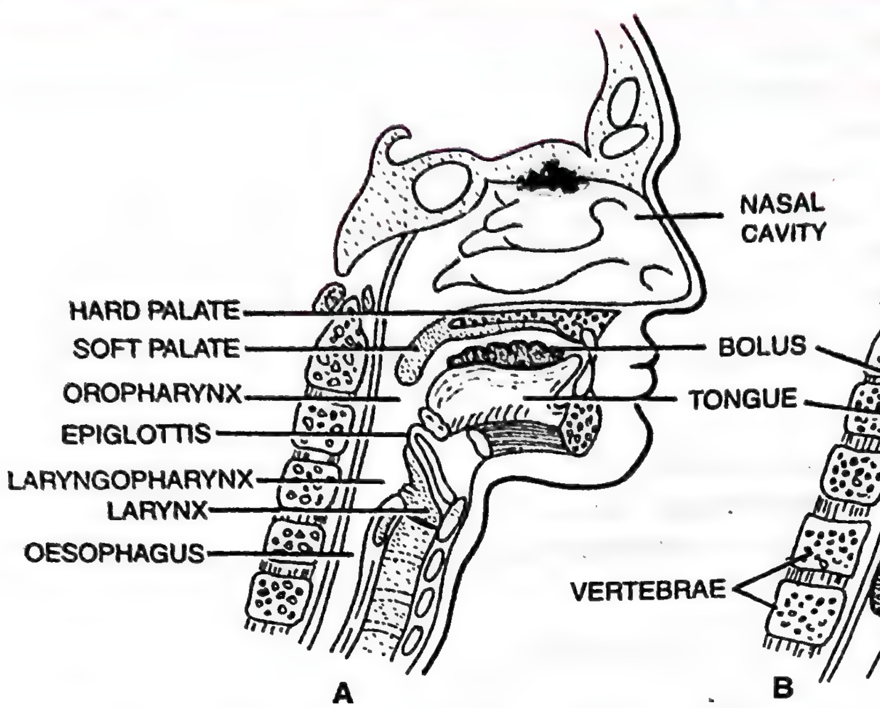


Fig. 16.18. Swallowing. A, Position of structures prior to swallowing. B, During swallowing, the tongue rises against the palate, the nose is closed off, the epiglottis seals off the larynx and the bolus is passed into the oesophagus.

Peristalsis

During the oesophageal phase of swallowing, food is pushed through the oesophagus by involuntary muscular movements called **peristalsis.**

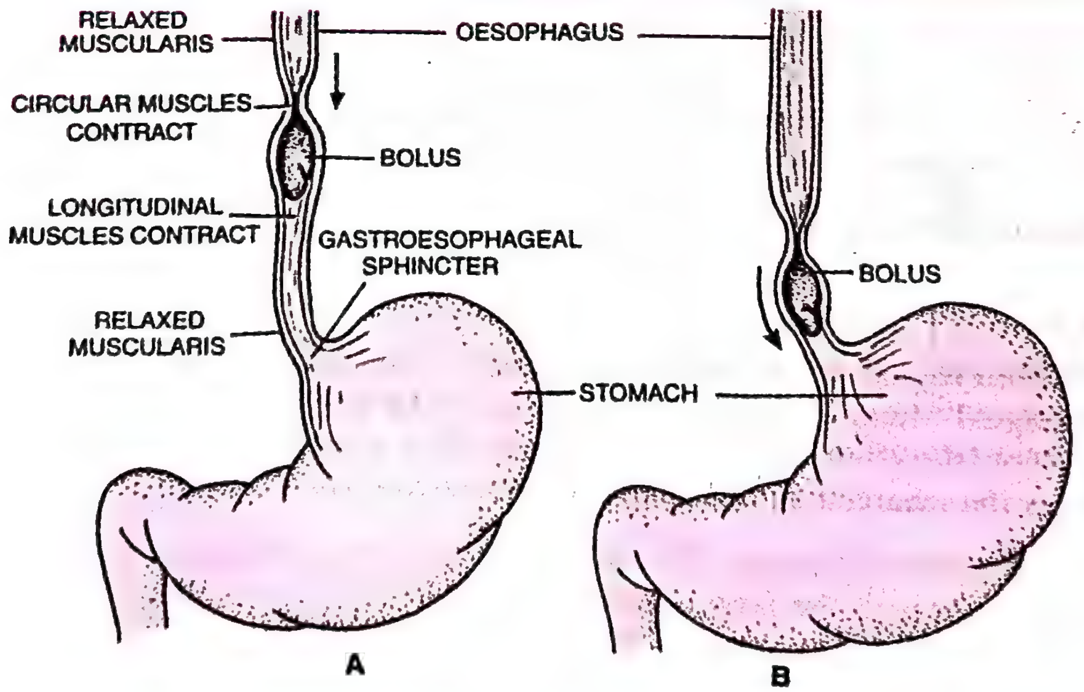


Fig. 16.19. Peristalsis in oesophagus.

Peristalsis is produced by involuntary contraction of circular muscles in the oesophagus lying just above and around the top of the bolus and simultaneous contraction of the longitudinal muscles lying around the bottom of and just below the bolus. Contraction of the longitudinal muscles shortens the lower part of the oesophagus, pushing its walls outward so that it can receive the bolus. After this circular muscles of the oesophagus relax. The contractions are repeated in a wave that moves down the oesophagus, pushing the food towards the stomach. There is least peristaltic movement in the rectum of human being.

Physiology of Digestion

Basic Mechanism of Digestion

Carbohydrates, fats, proteins and nucleic acids occur in food in the form of large and complex insoluble **macromolecules** or **polymers**. The polymers are made up of small soluble sub unit molecules called **monomers.** The monomers in the polymers of these foods are held together by **"anhydrobonds"** (*i.e.*, bonds formed by the removal of water). When polymers are made to react with water in the presence of enzymes, these polymers break down into their monomers. This is their **digestion.** Chemically, it is their **'hydrolysis'**. In other words digestion is a process in which the polymers of carbohydrates, fats, proteins and nucleic acids are broken down into their monomers by the addition of water with the help of enzymes. These enzymes are called **hydrolases** (general term for digestive enzymes). Largest variety of digestive enzymes are found in omnivores. Hydrolases are of four main types : Carbohydrases, Proteinases, lipases and nucleases.

1. **Carbohydrases** (= Carbohydrate-digestive enzymes). (i) **Amylases** split polysaccharides (*e.g.*, starch) into disaccharides (*e.g.*, maltose, sucrose, isomaltose, dextrins). (ii) Disaccharidases are split by maltase, sucrase, lactase, isomaltase and dextrinase into monosaccharides (glucose, fructose, galactose).

2. **Proteinases** (= Protein-digesting enzymes). Pepsin splits proteins into peptones and proteoses, trypsin changes proteins into dipeptides, chymotrypsin converts peptones into dipeptides. Carboxypeptides split proteoses into dipeptides, elastase converts elastin into dipeptides, aminopeptidases split peptides into aminoacids and dipeptidases change dipeptides into aminoacids. Proteinases (also called proteases) are generally released in inactive form because their active form would hydrolyse cellular and extracellular proteins of organism in the absence of food.

3. **Lipases** (= Fat-digestive enzymes). These hydrolyse fats into fatty acids and glycerol.

4. **Nucleases.** (i) **Deoxyribonuclease** and **ribonuclease** split DNA and RNA into deoxyribonucleotides and ribonucleotides respectively. (ii) **Nucleotidases** convert nucleotides into nucleosides and inorganic phosphate. (iii) **Nucleosidases** split nucleosides into nitrogenous bases and pentose sugar.

Thus digestion means the process of conversion of complex food substances into simple absorbable forms.

Digestion of Food

Digestion of Carbohydrates

Carbohydrates are of three kinds— polysaccharides, disaccharides, and monosaccharides. Polysaccharides and disaccharides are broken down to monosaccharides during the

process of digestion. Starch and cellulose are polysaccharides that are present in cereal grains, potato, tubers and fruits. Sucrose (in cane sugar), maltose (in malta), and lactose (in milk) are disaccharides. Enzymes which act on carbohydrates are called **carbohydrases**.

1. Digestion of Carbohydrates in the Oral Cavity

Action of Saliva. In oral cavity, the food is mixed with saliva. The saliva contains an enzyme called **salivary amylase (ptyalin)** which converts starch into maltose, isomaltose and small dextrins called α-dextrins. About 30 percent of starch is hydrolysed in the oral cavity. **Lysozyme** present in saliva acts as an antibacterial enzyme.

$$\text{Starch} \xrightarrow[pH\ 6.8]{\text{Salivary Amylase}} \text{Maltose} + \text{Isomaltose} + \alpha\text{-Dextrins}$$

Biocarbonate ions in saliva neutralise the acids in food. The **thiocyanate ions** of saliva act as antimicrobial agent and prevent infection by the microbes that often enter along with food. Mucus of the saliva moistens and dissolves some of the food and lubricates the oesophagus. Salivary amylase is absent in the saliva of many herbivorous mammals like cows and buffaloes and predatory carnivorous mammals like lions and tigers. However, saliva of pigs contains salivary amylase.

The gastric juice also contains small amount of gastric amylase but its action is inhibited by the highly acidic condition.

2. Digestion of Carbohydrates in the small intestine

In response to the action of stimuli received from the **vagus nerve** (10th carnial nerve) and **secretin** (a gastrointestinal hormone), the Brunner's gland (compound tubular glands of the duodenal epithelium) secretes a large amount of viscous, enzyme-free, alkaline and watery **mucoid fluid**. This secretion enables the duodenum to withstand the acidic chymes entering from the stomach, until it is neutralised by the alkaline pancreatic juice and bile. The mucus is secreted by the goblet (mucous) cells, where as water and electrolytes are secreted by the **enterocytes** present on the intestinal **crypts**. The mucus protects the duodenal wall from getting digested. Digestion of most of the nutrients takes place in the duodenum under the action of various enzymes.

(i) **Action of Pancreatic Juice**. The pancreatic juice contains starch digesting enzyme, called pancreatic **α-amylase** which converts starch into maltose, isomaltose and α-dextrins. Bicarbonte of the pancreatic juice neutralises hydrochloric acid of the chyme (semifluid mass) that enters the duodenum.

$$\text{Starch} \xrightarrow[\alpha\text{-Amylase}]{\text{Pancreatic}} \text{Maltose} + \text{Isomaltose} + \alpha\text{-Dextrins}$$

(ii) **Action of Intestinal Juice**. Intestinal juice contains **maltase, isomaltase, sucrase (invertase), lactase** and **α- Dextrinase** which act as follows :

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose} + \text{Glucose}$$

$$\text{Isomaltose} \xrightarrow{\text{Isomaltase}} \text{Glucose} + \text{Glucose}$$

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose} + \text{Fructose}$$

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose} + \text{Galactose}$$

$$\alpha\text{- Dextrins} \xrightarrow{\alpha\text{- Dextrinase}} \text{Glucose}$$

Lactose Intolerance. Only human being can digest lactose present in the milk, but with advancing age, they produce little or no lactase. In such persons, the lactose of milk remains undigested and is fermented in the intestine producing gases and acids. This results in flatulence, intestinal cramps and diarrhoea. So these persons should take yoghurt or curd as lactose is fermented into lactic acid in them. This does not pose any digestive problem to them.

Digestion of Proteins

Proteins are made up of **amino acids**. So proteins are broken down to amino acids during the process of digestion. Enzymes that hydrolyse proteins are called **proteases** or **peptidases**. Many of these enzymes are secreted in their inactive forms called **proenzymes** as their active forms would hydrolyse cellular and extracellular proteins of organisms itself. Inactive forms of enzymes are converted to their active forms at the sites of their actions.

Saliva does not contain any protein digesting enzyme. So digestion of proteins does not occur in the oral cavity. However, saliva can denature the uncooked natural proteins such as that present in raw egg, unboiled milk or uncooked germinating seeds.

1. Digestion of Proteins in the Stomach

Action of Gastric Juice. The stomach normally stores the food for 4 – 5 hours. The gastric glands of the stomach secrete gastric juice. It contains **hydrochloric acid**, proenzymes— **pepsinogen** and **prorennin**. Hydrochloric acid maintains a strongly acidic *p*H of about 1.5 to 2.5 in the stomach. *p*H of infants' gastric juice is 5.0. HCl kills bacteria and other harmful organisms that may be present alongwith food. HCl converts pepsinogen and prorennin into pepsin and rennin respectively. Once pepsin is formed it changes pepsinogen into pepsin. Such an activation is called **autocatalytic reaction**. *Pepsin and rennin are absent in invertebrates*. The thick acidic mixture of gastric juice and semidigested food formed in the stomach is called **chyme**. Various reactions are summarized below :

$$\underset{\text{(Proenzyme)}}{\text{Pepsinogen}} \xrightarrow{\text{HCl}} \text{Pepsin}$$

$$\text{Proteins} \xrightarrow{\text{Pepsin}} \text{*Peptones and **Proteoses \{peptides***\}}$$

$$\underset{\text{(Proenzyme)}}{\text{Prorennin}} \xrightarrow{\text{HCl}} \text{Rennin}$$

$$\underset{\text{(Milk protein)}}{\text{Casein}} \xrightarrow{\text{Rennin}} \text{Paracasein}$$

$$\text{Paracasein + Ca} \longrightarrow \text{Calcium paracaseinate (curd)}$$

$$\text{Calcium paracaseinate} \xrightarrow{\text{Pepsin}} \text{Peptones}$$

***Peptone** — a large protein fragment produced by the action of enzymes on proteins in the first stages of protein digestion.

****Proteose** — a product of the hydrolytic decomposition of protein.

*****Peptide** — a molecule consisting of two or more amino acids.

- Rennin is present in the infants' stomach. It is absent in the adults.
- Pepsin can digest even collagens of connective tissue fibres, but not keratins of horn, hair, skin or nail.
- The invertebrates do not secrete pepsin and rennin.
- Rennet tablets which contain rennin are extracted from calf gastric mucosa. These tablets are often used commercially for coagulating the casein of milk to curd.
- Sometimes chyme is squeezed into oesophagus. This causes burning of some cells. It is called **heart burn** (= **pyrosis** or hyper acidity). Heart burn has nothing to do with the heart. Though the pain is near the heart, it is caused by the regurgitation of acid from the stomach into the oesophagus.
- Since pepsin is secreted as pepsinogen (inactive form of pepsin), it poses no threat to the stomach. The mucus also protects the epithelial surface from excoriation by HCl and digestion by proteases.

Functions of Hydrochloric Acid. Hydrochloric acid serves the following functions :

(i) It kills harmful bacteria.

(ii) It provides acidic medium in the stomach for gastric digestion.

(iii) It changes pepsinogen into pepsin and prorennin into rennin.

(iv) It softens the food and dissolves the cement materials between the cells of the food in order to make them readily available for enzyme action.

(v) It stops the action of salivary enzyme.

(vi) It is believed to control the opening and closing of pyloric opening of the stomach.

2. **Digestion of Proteins in the small intestine**

(i) **Action of Pancreatic Juice.** Pancreatic juice contains proenzymes— **trypsinogen, chymotrypsinogen** and **procarboxypeptidase** and enzyme **elastase**. All these are concerned with proteins digestion. The bile provides alkaline medium for various reactions. All these reactions are summarised below:

$$\underset{\text{(Proenzyme)}}{\text{Trypsinogen}} \xrightarrow[\text{of intestinal juice}]{\text{Enterokinase}} \text{Trypsin}$$

$$\underset{\text{(Proenzyme)}}{\text{Chymotrypsinogen}} \xrightarrow{\text{Trypsin}} \text{Chymotrypsin}$$

$$\underset{\text{(Proenzyme)}}{\text{Procarboxypeptidase}} \xrightarrow{\text{Trypsin}} \text{Carboxypeptidase}$$

Proteins, peptones and proteoses are acted upon as given below

$$\text{Proteins} \xrightarrow{\text{Trypsin}} {}^{*}\text{Dipeptides}$$

$$\text{Peptones} \xrightarrow{\text{Chymotrypsin}} \text{Dipeptides}$$

$$\text{Proteoses} \xrightarrow{\text{Carboxypeptidases}} \text{Dipeptides}$$

$$\underset{\text{(Proenzyme)}}{\text{Proelastase}} \xrightarrow{\text{Trypsin}} \text{Elastase}$$

*Dipeptides contain two amino acids.

$$\text{Elastin} \xrightarrow{\text{Elastase}} \text{Dipeptides}$$

In predatory animals, trypsin can hydrolyse fibrinogen of blood into fibrin leading to blood coagulation. Mostly vertebrates do not have proteases for digesting some fibrous animal proteins such as hair, keratin, silk fibroin and wool protein. However, some invertebrates like insects secrete enzymes for digesting such fibrous proteins. Therefore, some insects destroy silk fabrics and woollen garments.

(ii) **Action of Intestinal Juice.** Intestinal juice (succus entericus) contains **enterokinase (enteropeptidase)**– also called **"activator enzyme"**, **aminopeptidases** and **dipeptidases.** Enterokinase converts trypsinogen of pancreatic juice into trypsin. Actions of other enzymes are summarized below :

$$\text{Peptides} \xrightarrow{\text{Aminopeptidases}} \text{Amino acids}$$

$$\text{Dipeptides} \xrightarrow{\text{Dipeptidases}} \text{Amino acids}$$

Differences between Pepsin and Trypsin

Pepsin	*Trypsin*
1. It is a protease in the stomach.	1. It is a protease in the intestine.
2. It functions at an acidic *p*H.	2. It functions at an alkaline *p*H.
3. It can hydrolyse collagen.	3. Digestion of collagen is limited.
4. It can hydrolyse milk proteins.	4. It cannot hydrolyse milk proteins.

Digestion of Fats

Almost the entire fat portion of the diet consists of triglycerides (neutral fats) which are made up of three fatty acid molecules and a single glycerol molecule. In fact glyceride is an ester of glycerol compounded with an acid. There are present mono-, di- and tri-glycerides. **Steapsin** or fat digesting enzymes are soluble in water, but insoluble in fats and oils. However, fats and oils are insoluble in water. Term **lipase** is usually used as fat digestive enzyme.

Saliva contains no lipase. The stomach also lacks any fat-emulsifying agent. However, the gastric juice contains small amount of **gastric lipase** which converts some fats into monoglycerides and fatty acids. Fat is largely digested in the small intestine. Bile salts of the bile break down fat droplets into many small ones by reducing the surface tension of fat droplets. This process is called **emulsification**. This increases lipase action on fat. Lipase is present in the pancreatic juice and intestinal juice. **Pancreatic lipase** *is the principal enzyme for the digestion of fat*. In addition, an **intestinal lipase** is also helpful in the digestion of fat. The pancreatic lipase converts emulsified fats (triglyceride fats), first into diglycerides and then into monoglycerides, releasing a fatty acid at each step. The intestinal lipase converts remaining fats into monoglycerides and fatty acids. Finally all fats are converted into fatty acids, glycerol and monoglycerides.

$$\underset{\text{(triglyceride)}}{\text{Fat}} \xrightarrow{\text{Bile}} \text{Emulsified fat}$$

$$\text{Emulsified fat (triglyceride)} \xrightarrow[\text{lipase}]{\text{Pancreatic}} \text{Fatty acid + Diglyceride}$$

$$\text{Diglyceride} \xrightarrow[\text{lipase}]{\text{Pancreatic}} \text{Fatty acid + Monoglyceride}$$

$$\text{Monoglyceride} \xrightarrow[\text{lipase}]{\text{Pancreatic}} \text{Fatty acid + Glycerol}$$

Lipase is activated by the bile.

Digestion of Nucleic Acids

Nucleic acids are digested in the small intestine. The enzymes which digest nucleic acids are present in the pancreatic juice and intestinal juice.

(a) **Pancreatic juice.** It contains two **nucleases** : **Deoxyribonuclease (DNase)** and **Ribonuclease (RNase)**, which act as follows :

$$\text{DNA} \xrightarrow{\text{DNase}} \text{Deoxyribonucleotides}$$

$$\text{RNA} \xrightarrow{\text{RNase}} \text{Ribonucleotides}$$

(b) **Intestinal juice.** It contains enzymes; **nucleotidases** and **nucleosidases** which act as under.

$$\underset{\text{(Deoxyribonucleotides/Ribonucleotides)}}{\text{Nucleotides}} \xrightarrow{\text{Nucleotidases}} \underset{\text{(Deoxyribonucleosides/Ribonucleosides)}}{\text{Nucleosides}} + \text{Inorganic phosphate}$$

$$\underset{\text{(Deoxyribonucleosides/Ribonucleosides)}}{\text{Nucleosides}} \xrightarrow{\text{Nucleosidases}} \underset{\text{(Purines/Pyrimidines)}}{\text{Nitrogenous bases}} + \underset{\text{(Deoxyribose/Ribose)}}{\text{Pentose sugar}}$$

Chyle. It is a white or pale yellow fluid taken up by the lacteals (lymph capillaries) from the intestine during digestion. It mainly consists of absorbed fat.

Summary of the Action of Digestive Enzymes in Human beings

Emzyme	*Site of Action*	*Substrate*	*Products of Action*
	Saliva or Salivary Juice (Salivary glands)		
Salivary-Amylase (= Ptyalin)	Mouth	Strach (Polysaccharides)	Disaccharides (few)
	Gastric Juice (Stomach)		
(i) Pepsin	Stomach	Proteins	Peptides
(ii) Rennin	Child's stomach	Casein (milk protein)	Calcium Paracaseinate
(iii) Gastric Lipase	Stomach	Small amount of fat	Glycerol and fatty acids.

Pancreatic Juice (Pancreas)			
(i) Pancreatic α-Amylase	Small intestine	Strach	Disaccharides
(ii) Trypsin	Small intestine	Proteins	Dipeptides
(iii) Chymotrypsin	Small intestine	Peptones	Dipeptides
(iv) Elastase	Small intestine	Elastin (Protein)	Dipeptides
(v) Carboxypeptidases	Small intestine	Proteoses	Dipeptides
(vi) Pancreatic Lipase	Small intestine	Fats (Trigly-cerides)	Fatty acids and glycerol
(vii) Nucleases			
(a) Deoxyribonuclease	Small intestine	DNA	Deoxyribonucleotides
(b) Ribonuclease	Small intestine	RNA	Ribonucleotides
Intestinal juice (Small Intestine)			
(i) Enterokinase	Small intestine	Trypsinogen	Trypsin
(ii) Aminopeptidases	Small intestine	Peptides	Amino acids
(iii) Dipeptidases	Small intestine	Dipeptides	Amino acids
(iv) Disaccharidases	Small intestine	Disaccharides	Monosaccharides
(v) Intestinal Lipase	Small intestine	Fats (trigly-cerides)	Fatty acids and glycerol.
(vi) Nucleotidases	Small intestine	Nucleotides	Nucleosides and inorganic phosphate
(vii) Nucleosidases	Small intestine	Nucleosides	Nitrogenous bases and pentose sugar.

Neural Regulation of Digestion

The activities of the gastro-intestinal tract are under neural and hormonal control for proper coordination amongst different parts. The gastrointestinal tract is innervated by an intrinsic nervous system as well as by extrinsic nerves. The **intrinsic neural* system** is also called, the **enteric neural system**, consists of (i) the Meissner's plexus situated in the submucosa and (ii) the Auerbach's plexus situated in the muscular layer. The enteric neural system controls most of the gastrointestinal functions like secretion and motility.

The **extrinsic innervation** of the gut consists of parasympathetic and sympathetic nerves which can modify the activity of the intrinsic neural system in response to reflex activity initiated from the GIT itself or from other parts of the body.

The sight, smell and presence of food in the gastrointestinal tract act as a stimuli for the secretion of saliva. This happens by the stimulation of vagus nerve. Feeling of hunger at a particular time, when regularly food is taken, is an example of **conditional reflex**.

Role of Gastrointestinal Hormones

Following hormones regulate the digestive secretions :

1. **Gastrin.** This hormone is secreted by **gastrin cells** (= G-cells) in the pyloric region of the stomach. It stimulates gastric glands to secrete and release the gastric juice. It also stimulates gastric mobility.

* In humans the term 'neural' is used in place of 'nervous'.

2. **Enterogastrone.** (= Gastric Inhibitory Peptide— **GIP**). It is secreted by the duodenal epithelium. It inhibits gastric secretion and motality. It slows gastric contraction, hence it is also called gastric inhibitory peptide.

3. **Secretin.** *It was the first hormone to be discovered by scientists.* It is secreted by the epithlium of duodenum. It releases bicarbonates in the pancreatic juice. It increases secretion of bile. It decreases gastric secretion and motality.

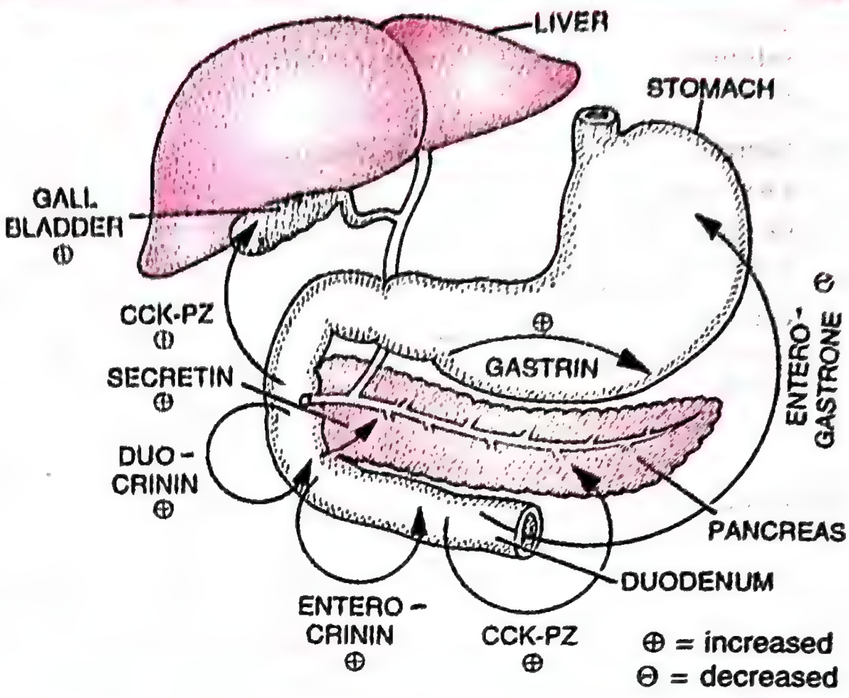


Fig. 16.20. Hormonal regulation of digestive secretions.

4. **Cholecystokinin pancreozymin (CCK-PZ).** The word cholecystokinin is derived from three roots: *Chol* meaning bile, cyst meaning bladder and *kinin* meaning to remove. The word pancreozymin is derived from pancreas and *zymin*, which means enzyme producer. This hormone is secreted by the epithelium of entire small intestine. It stimulates the gall bladder to release bile and pancreas to secrete and release digestive enzymes in the pancreatic juice.

5. **Duocrinin.** It is secreted by the duodenal epithelium and stimulates the Brunner's glands to release mucus and enzymes into the intestinal juice.

6. **Enterocrinin.** It is secreted by the epithelium of entire small intestine. It stimulates the crypts of Lieberkuhn to release enzymes into the intestinal juice.

7. **Vasoactive Intestinal Peptide (VIP).** It is secreted by the epithelium of entire small intestine. It dilates peripheral blood vessels of the gut. It also inhibits gastric acid secretion.

8. **Villikinin.** It is secreted by the epithelium of entire small intestine. It accelerates movement of villi.

9. **Somatostatin (SS).** Somatostatin secreted by the Delta cells of islets of Langerhans of the pancreas inhibits the secretion of glucagon by aplha cells and insulin by beta cells. Somatostatin produced by argentaffin cells of gastric and intestinal glands suppresses the release of hormones from the digestive tract.

10. **Pancreatic Polypeptide (PP).** It is secreted by the pancreatic polypeptide cells (also called PP cells or F-cells) of islets of Langerhans. It inhibits the release of pancreatic juice from the pancreas.

Summary of Gastrointestinal Hormones

Hormone	Source	Traget organ	Action
1. Gastrin	Stomach	Stomach	Stimulates gastric glands to secrete and release the gastric juice. It also stimulates gastric mobility and HCl secretion.

2. Entero-gastrone (= Gastric Inhibitory Peptide-GIP)	Duodenum	Stomach	Inhibits gastric secretion and motility (slows gastric contraction).
3. Secretin First hormone discovered by scientists	Duodenum	Pancreas Liver Stomach	Releases bicarbonates in the pancreatic juice. Increases secretion of bile. Decreases gastric secretion and motality.
4. Cholecystokinin-Pancreozymin (CCK-Pz)	Small Intestine	Gall bladder and Pancreas	Contracts the gall bladder to release bile. Stimulates pancreas to secrete and release digestive enzymes in the pancreatic juice.
5. Duocrinin	Duodenum	Duodenum	Stimulates the Brunner's glands to release mucus and enzymes into the intestinal juice.
6. Enterocrinin	Small intestine	Small intestine	Stimulates the Crypts of Lieberkuhn to release enzymes into the intestinal juice.
7. Vasoactive Intestinal Peptide (VIP)	Small intestine	Small intestine and stomach	Dilates peripheral blood vessels of gut. Inhibits gastric acid secretion.
8. Villikinin	Small intestine	Small intestine	Accelerates movements of villi.
9. Somatostatin (SS)	Delta cells of islets of Langerhans of pancreas.	Pancreas, Gastro-intestinal tract,	Inhibits the secretion of glucagon by alpha cells and inslulin by beta cells. It also inhibits a absorption of nutrients from the gastrointestinal tract.
	Argentaffin cells of gastric and intestinal glands.	Gastrointestinal tract.	Supresses the release of hormones from the digestive tract.
10. Pancreatic Polypeptide (PP)	Pancreatic Poly-peptide cells	Pancreas	Inhibits the release of pancreatic juice from the pancreas.

Absorption of Nutrients

Meaning of Absorption. Absorption is a process by which nutrients pass from the alimentary canal into the blood and lymph through its mucous membrane.

Nutrients to be absorbed. Amino acids, monosaccharides, fatty acids, glycerol, salts (electrolytes), vitamins and water are to be absorbed.

Site of Absorption. About 90% of all absorption of nutrients occurs in the small intestine, the other 10% occurs in the stomach and large intestine. Some water and salts, alcohol, some drugs such as aspirin, and moderate amounts of sugar are absorbed in the **stomach.** Water and products of bacterial digestion (amino acids and vitamin B complex and vitamin K) are absorbed in the large intestine. Thus absorption mainly occurs in the small intestine.

Absorption of Different Nutrients. Absorption occurs by **simple diffusion, osmosis, facilitated transport** and **active transport.**

1. **Absorption of Monosaccharides.** All carbohydrates are absorbed as monosaccharides in stomach and jejunum. Glucose and galactose are absorbed by **active transport**. Sodium pump of the cell membrane helps in its active take up. Fructose is absorbed by **facilitated transport**. Glucose, galactose and fructose are absorbed into the blood capillaries. *The most rapidly transported monosaccharide is galactose* with glucose running a close second.

2. **Absorption of Amino acids.** Amino acids are absorbed by **active transport** and some amino acids are absorbed by facilitated transport. It occurs mainly in the duodenum and jejunum. Normally 95–98% of amino acids are absorbed in the small intestine. They also enter the blood stream (Fig. 16.22).

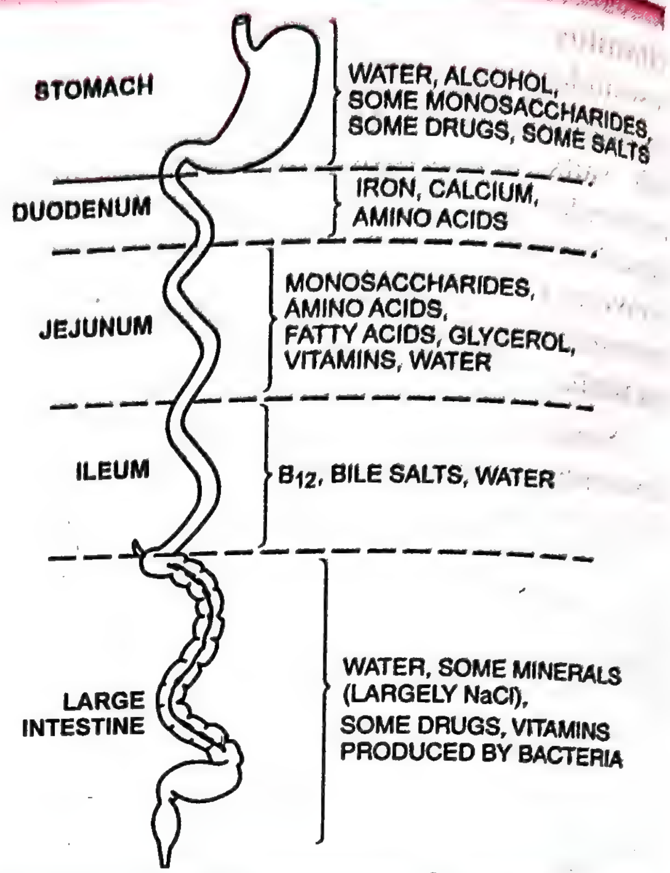


Fig. 16.21. Sites of absorption of nutrients and drugs in the gastrointestinal tract.

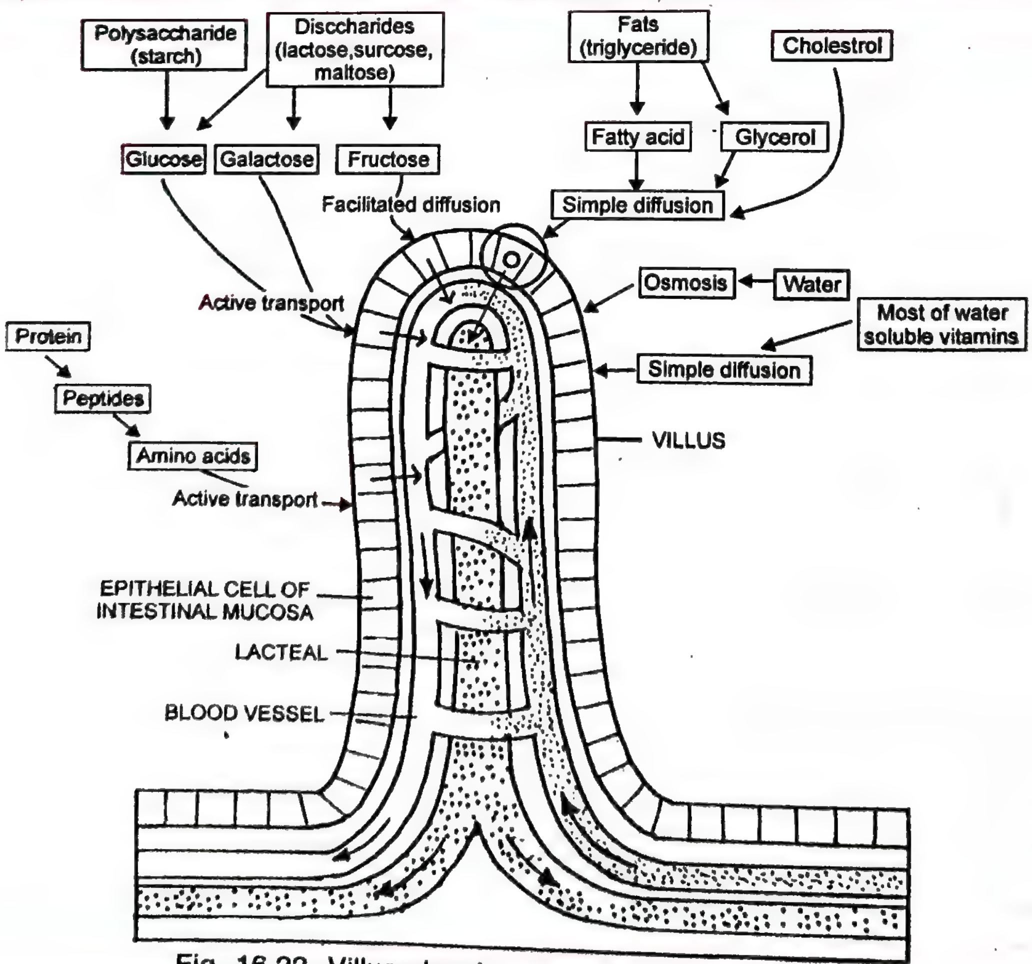


Fig. 16.22. Villus showing absorption of nutrients.

3. **Absorption of Fatty acids and Glycerol** (= Absorption of fat) **and fat soluble vitamins.** All these nutrients are absorbed via *simple diffusion*. Fatty acids and glycerol are insoluble in water, therefore, they cannot reach the blood stream directly. They are first incorporated into small, spherical, water soluble droplets called **micelles** with the help of the bile salts and phospholipids in the intestinal lumen. A micelle is an aggregate of many molecules. From the micelles fatty acids, glycerides, sterols and fat soluble vitamins are absorbed into the intestinal cells by diffusion where they are resynthesized in the ER and are converted into very small fat molecules (droplets) called **chylomicrons.** The latter are released from the intestinal cells into the lymph present in the lymphatic capillaries, the **lacteals.**

Small quantities of short chain fatty acids are absorbed directly into the blood by diffusion rather than into the lymph. Fatty acids, glycerol and vitamins are absorbed in jejunum.

Differences between Micelles and Chylomicrons

Micelles	*Chylomicrons*
1. The products of fat digestion are incorporated into small, spherical, water soluble molecules called micelles with the help of bile salts and phospholipids.	1. The products of fat digestion are used for synthesizing new fats which are released by the intestinal cells into the lymph, in the form of droplets called chylomicrons.
2. This is the form in which digested fats are absorbed into the intestinal cells.	2. This is the form in which the synthesized fats are liberated from the intestinal cells.

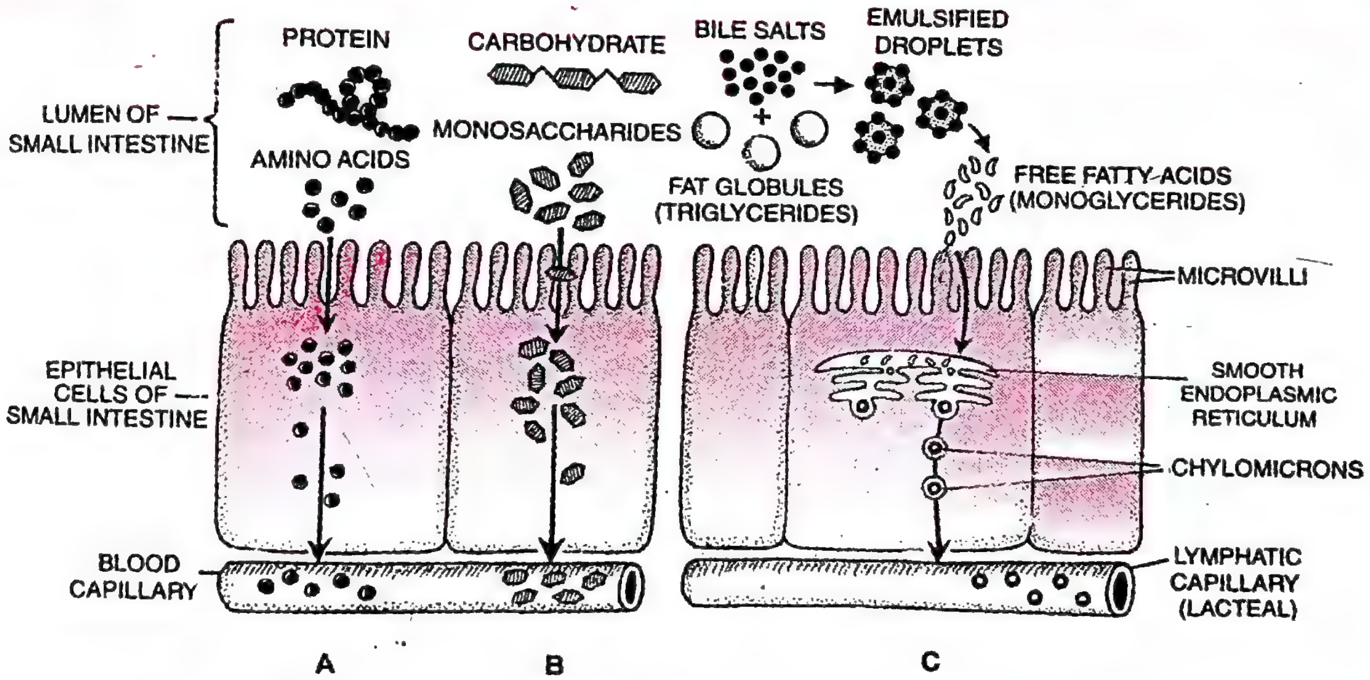


Fig. 16.23. Epithelial cells of small intestine showing absorption of nutrients.
A, Absorption of aminoacids. B, Absorption of monosaccharides. C, Absorption of fatty acids.

4. **Absorption of Water.** About 90% of all water absorption occurs in the small intestine by **osmosis** from the lumen of the small intestine through epithelial cells and into the blood capillaries in the villi. The absorption of water from the small intestine is associated with the absorption of electrolytes and digested food in order to maintain an osmotic balance with the blood. Absorption of water also occurs in the stomach and the large intestine.

5. **Absorption of Salts (Electrolytes).** Sodium is absorbed from small intestine by active transport. This process is coupled to the movement of glucose, as mentioned earlier. Several other ions, including calcium, potassium, magnesium, iron and phosphate are absorbed by active transport. Calcium absorption is enhanced by vitamin D and parathormone (hormone secreted by parathyroid glands). Chloride ions can be absorbed by diffusion or active transport. Salts are also absorbed into the blood capillaries. Most ions are actively absorbed throughout the small intestine. Calcium absorption is mainly limited to the duodenum. Almost all iron absorption occurs in the duodenum. Bile salts are absorbed in ileum.

6. **Absorption of Water Soluble Vitamins.** Most of water soluble vitamins such as the vitamin B complex, vitamin C and vitamin P are absorbed by simple diffusion into the blood capillaries. But reabsorption of vitamin B_{12} requires combination with Castle's intrinsic gastric factor produced by the stomach for its absorption.

7. **Absorption of Alcohol.** Because alcohol is lipid soluble, it begins to be absorbed in the stomach. However, the surface area for absorption is much greater in the small intestine than in the stomach, so when alcohol passes into the duodenum, it is absorbed more rapidly.

Thus amino acids, monosaccharides, short chain fatty acids, minerals, water soluble vitamins, and water are absorbed into the blood and fatty acids, glycerol, glycerides and fat soluble vitamins are absorbed into the lymph.

The Summary of Absorption in different parts of Digestive System

Mouth (Oral Cavity)	Stomach	Small intestine	Large intestine
Certain drugs coming in contact with the mucosa of mouth and lower side of the tongue are absorbed into the blood capillaries lining them.	Absorption of water, simple sugars and alcohol etc. takes place.	Principal organ for absorption of nutrients. The digestion is completed here and the final products of digestion such as glucose, fructose, fatty acids, glycerol and amino acids are absorbed through the mucosa into the blood stream and lymph.	Absorption of water, some minerals and drugs takes place.

Assimilation of Proteins, Carbohydrates and Fats

The absorbed food materials are transported by blood and lymph. Lymph is finally transferred to the blood circulation. The blood transports absorbed food materials to different body cells where food materials become integral component of the living protoplasm and are used for energy, growth and repair. This is called **assimilation** of food.

(i) **Proteins. Amino acids** are not stored but are taken up by the cells in connection with the synthesis of proteins. Proteins are used for growth, repair, etc. Excess amino acids can be converted into glucose and then to fat and are thus stored. This is an irreversible reaction. Amino acids can also be converted to glucose and used as fuel for the cell. During their conversion to glucose the amino acids are deaminated (removal of amino groups — NH_2). The liver is chief site for **deamination**, *i.e.*, a process by which the amino group is removed from the amino acids resulting in the production of ammonia. The ammonia is soon converted into urea, which is filtered from the blood in the kidney.

(ii) **Carbohydrates.** The excess of the **monosaccharides**; the glucose, fructose and galactose are usually stored in the liver and muscle cells in the form of glycogen (glycogenesis). Whenever, there is a deficiency of glucose in the blood the glycogen is converted into glucose (glycogenolysis). Muscle glycogen is utilized during muscle contraction. Glucose is utilized in the production of energy for various body activities. A considerable amount of glucose is converted into fat and stored as such.

(iii) **Fats.** The **fat** is stored in the fat deposits of the body, such as subcutaneous layers, mesenteries, etc. The fat stored is a readily available source of fuel for the cells. Fat has important insulating properties in connection with the conservation of heat and maintenance of body temperature. Fat also plays a protective role as filling or around packing material and between organs. In the liver phospholipids are formed which are returned to the blood to be used by all the cells. In the liver cells the fats are converted into amino acids and carbohydrates.

Vitamins, salts and water are also useful for various metabolic processes.

Egestion (= Defecation)

Meaning of Egestion. The elimination of faeces from the alimentary canal is called **egestion** or **defecation**. The faeces is waste matter discharged from the alimentary canal.

Mechanism of Egestion. Peristalsis gradually pushes the indigestible materials of the small intestine into the large intestine or colon. Normally 1500 ml of chyme passes into the large intestine per day. The colon absorbs most of the water. It also absorbs electrolytes, including soduim and chloride from the chyme. The epithelial cells of the colon also excrete certain salts such as iron and calcium from the blood. *Escherichia coli* (bacterium) lives in the colon which feeds on undigested matter. This bacterium, in turn, produces vitamin B_{12} (cobalamin), vitamin K, vitamin B_1 (thiamine) and vitamin B_2 (riboflavin) which are absorbed by the wall of colon. Consequently, the chyme converts into semisolid faeces. As the pellets of faeces enter the rectum, distension of rectal wall induces the feeling of defecation due to a **"defecation reflex"**. This reflex initiates peristalsis in the last part of the colon (sigmoid colon) and the rectum, forcing the faeces towards anus. As the faeces reaches anus, involuntary relaxation of the internal anal sphincter and voluntary relaxation of external anal sphincter cause defecation. Voluntary contractions of the diaphragm and abdominal muscles forces the sphincters open, and the faeces is expelled through the anus (contraction of the abdominal muscles and lowering of the diaphragm increases the intra-abdominal pressure which aids in the process of defecation).

In infants, the defecation occurs by reflex action without the voluntary control of the external anal sphincter.

Constituents of Faeces. The faeces consists of about three-fourth water and one-fourth solid matter. Of the solid matter is about 3 per cent bacteria, 10 to 20 per cent fat, 2 to 3 per cent protein, about 15 per cent inorganic matter and 30 per cent undigested roughage and dry constituents of digested juices. Dead mucosal cells, mucus and cholesterol also occur in the faeces. Its brown colour is due to brown pigments, **stercobilinogen** and **stercobilin,** which are derivatives of bilirubin.

Balanced Diet

A diet is said to be balanced when various nutritional materials *i.e.*, proteins, carbohydrates, fats, minerals, vitamins, roughage (indigestible fibrous material present in the food) and water are present in sufficient amount and proper proportion. Various constituents of the balanced diet provide energy, growth, repair, replacement of cells, and physiological regu-

lation. Our food should contain the various nutrients in such proportions as can satisfy all the needs of our body. It has been discovered that of our energy requirement, we obtain about 50% from carbohydrates, 35% from fats and 15% from proteins. Thus, we daily require about 400 to 500 grams of carbohydrates, 60 to 70 grams of fats and 65 to 75 grams of proteins. Balanced diet of each individual can be determined according to his or her needs.

Nutritional Requirements of Humans

(i) **Energy yeilding nutrients.** Carbohydrates and lipids (fats) are chief energy giving nutrients. Proteins can also give energy.

(ii) **Body building nutrients.** Proteins are chief body building nutrients.

(iii) **Metabolic regulators,** *e.g.*, vitamins, water and mineral salts.

(iv) **Hereditary substances,** *e.g.*, Nucleic acids (DNA and RNA).

Besides carbohydrates, proteins, fats, vitamins, minerals and water, **roughage** is also essential in diet.

Nutritional Roles of Food Constituents

1. **Carbohydrates.** (i) These are found in sugar, jam, cereals, bread, biscuits, potatoes, fruits and vegetables.

(ii) Carbohydrates are classified as monosaccharides (*e.g.*, glucose, fructose, galactose), disaccharides (*e.g.*, sucrose, maltose, lactose) and polysaccharides (*e.g.*, starches, glycogen, cellulose, dextrins).

(iii) Carbohydrates are absorbed from the alimentary canal as monosaccharides.

(iv) All polysaccharides can not be digested by human beings, for example, cellulose present in vegetables passes through the alimentary canal almost unchanged.

(v) Carbohydrates are used primarily as sources of chemical energy to be either metabolised immediately as glucose or stored as glucogen. The synthesis of glycogen is called **glycogenesis.**

(vi) If carbohydrate is eaten in excess it is converted into fat and stored in the body. Carbohydrates may be changed into amino acids. When there is an adequate supply of carbohydrate in diet, protein does not need to be used to provide energy and heat.

(vii) Carbohydrates are more suitable for the production of energy in the body than proteins and fats because carbohydrate molecules contain relatively more oxygen than the others, hence require less molecular oxygen for oxidation. So athletes, labourers doing heavy work and mountaineers should take high carbohydrate diets.

(viii) Carbohydrates are also stored in the body cells as glycogen and are used for the production of energy whenever required.

(ix) The liver can store enough glycogen to maintain blood glucose level for several hours. Under acute starved conditions, the liver cells begin to convert amino acids and the glycerol into glucose. Such production of new glucose is called **gluconeogenesis.**

2. **Proteins.** (i) Proteins are made up of a number of units, called **amino acids.** 22 amino acids have been identified so far. Amino acids are divided into two categories : **essential** and **non-essential amino acids**. Essential amino acids are so called because they cannot be synthesized in the body and therefore, must be included in the diet. Eight amino acids (ten in children) are considered essential for human nutrition. These are isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. Non-essential amino acids are those which can be synthesized in the body. These are alanine, arginine,

asparagine, aspartic acid, cysteine, cystine, glutamic acid, glutamine, glycine, histidine, hydroxyproline, proline, serine and tryosine. Arginine and histidine are considered **semi-indispensable amino acids**. Amino acids can be classified into three groups depending on their reaction in solution : (a) **Neutral amino acids**, *e.g.*, glycine, alanine, serine, threonine, valine, leucine, isoleucine, phenylalanine, tryosine, tryptophan, histidine, proline, hydroxyproline, cysteine, cystine, methionine (last three are sulphur containing amino acids). (b) **Acidic amino acids**, *e.g.*, aspartic acid, glutamic acid. (c) **Basic amino acids**, *e.g.*, arginine, lysine.

Differences between Essential and Non-essential amino acids	
Essential Amino Acids	*Non-Essential Amino Acids*
1. Cannot be biosynthesized in the body.	1. Can be biosynthesized in the body.
2. They must be supplied with food in adequate amounts.	2. They need not be supplied with food.
3. They are eight in number, *e.g.*, methionine, threonine, etc.	3. They are 12 in number, *e.g.*, alanine, Arginine, etc.

(ii) Proteins can be classified as **first class proteins** and **second class proteins**. First class proteins contain all the essential amino acids in the correct proportions. They are derived almost entirely from animal sources and include meat, fish, milk and eggs. Second class proteins do not contain all the essential amino acids in the correct proportions. They are considered nutritionally inferior to animal proteins with respect to essential amino acids. They are mainly of vegetable origin. Examples of second class proteins are peas, beans and lentils, which are known as pulses. A small proportion of second class protein is to be found in other vegetables and in some of the mainly carbohydrate foods, such as bread and potatoes.

(iii) Proteins are used as structural components of tissues, as channels, transporters, regulatory molecules and enzymes.

(iv) Amino acids, the units of proteins, are required for the formation growth and repair of body cells. Therefore, the protein requirement rises during pregnancy and lactation. Infants and children, also need good quantity of proteins.

(v) If proteins are not provided properly, two deficiency diseases named **Marasmus** and **Kwashiorkor** are caused in children.

(vi) Amino acids are required for the formation of some secretions of the cells, *i.e.*, hormones (adrenaline and thyroxine).

(vii) Amino acids are also needed for the formation of blood proteins, *i.e.*, albumin, globulin, fibrinogen and prothrombin.

(viii) Amino acids are also required for the formation of products like heme of haemoglobin, the skin pigment melanin and purines and pyrimidines of nucleic acids.

(ix) Proteins can also be utilized as energy sources. Normally, this is a secondary function and becomes important only when there is not enough carbohydrate in the diet and stored fat is in less quantity.

(x) Some amino acids give rise to carbohydrates in the body.

(xi) When protein is eaten in excess, the nitrogenous part is detached and excreted by the kidneys and the remaining portion is converted into fat which is stored in the body.

3. **Fats** (Lipids). (i) Fats are divided into two group; animal and vegetable. **Animal fat** is found in milk, cheese, butter, eggs and meat and oily fish such as Cod. **Vegetable fat** is found in margarine (butter substitute made from animal or vegetable fats) and in vegetable oils. Nuts of various kinds are the best natural source of vegetable oil.

(ii) The fat cells of adipose tissue can store up to 95% of their volume of triglycerides (fats), and for this reason adipose tissues are often called the **fat depot** of body. Triglycerides are used as **fuel**. Fat is used for long term energy storage by animals.

(iii) Since fat oxidation gives about 2¼ times the energy yielded by the same weight of glycogen, so fat is more suitable as stored food. In man, 10–25 percent of total calorie requirement should be met with fat. Athletes, weight lifters and manual labourers should take more than 40 per cent of their food calorie from fats as it will fulfill their high caloric need.

(iv) The ratio of **saturated** and **unsaturated** fats should be low because an excess intake of saturated and unsaturated fats such as ghee, butter and hydrogenated vegetable fats increase cholesterol in the blood. Excess of fats, particularly saturated fats and cholesterol should be avoided by sedentary obese, old persons and patients of heart disease and high blood pressure.

(v) Some polyunsaturated fatty acids (with more than one double bond) are not synthesized in the body hence they must be supplied with food to avoid their deficiency. They are called **essential fatty acids**. The latter are present in many unsaturated vegetable oils like groundnut oil, sunflower oil and safflower oil. Linoleic, linolenic and arachidonic acids are most essential fatty acids (EFA).

(vi) Excess of carbohydrates are converted largely into fats for storage. Lambs and pigs store large amounts of fat in their body if they are kept on starch rich foods such as maize, cereals or gram.

(vii) Fat is useful in transport of the fat-soluble vitamins A, D, E and K.

(viii) It is present in the nerve sheaths and in the secretions of the sebaceous glands in the skin.

(ix) Fat is used in the formation of cholesterol and certain hormones.

(x) Fat provides support to certain organs, for example, the kidneys and the eyes.

(xi) Fats are important constituents of cell organelle.

Calorific Value of Carbohydrate, Protein and Fat

Carbohydrates, proteins and fats serve as the chief sources of energy in humans. These are oxidized and transformed into ATP, the chemical energy form used by cells for their various activities.

Because heat is the ultimate form of all energy, the energy value of food (or any fuel) is expressed in terms of a measure of heat energy it produces on combustion. The heat energy released by combustion of one gram of food is usually known as its gross **calorific value.** It is defined as the amount of heat produced in calories (cal) or in joules (J) from complete combustion of 1 gram food in a bomb calorimeter (a closed metal chamber filled with O_2). The calorific value is usually expressed in terms of kcal per gram or kilojoules per gram. (1kcal = 4.184kJ) One kilocalorie is the amount of heat energy needed to raise the temperature of one kilogram of water through 1°C (1.8°F). It is referred to kcal as the **Calorie** or to kJ as **Joules** (always capitalized). The calorific values of carbohydrates, proteins and fats are 4.1 kcal/g, 5.65 kcal/g and 9.45 kcal/g, respectively.

Physiologic Value of Carbohydrate, Protein and Fat

The actual amount of energy liberated *in the human body* due to combustion of 1g of food is the **physiologic value** of food. It is always less than gross calorific value calculated by bomb calorimeter. The physiologic values of carbohydrates, proteins and fats are 4.0 kcal/g, 4.0 kcal/g and 9.0 kcal/g respectively.

The Physiologic Value

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Calorific Value and Physiologic Value of Carbohydrate, Protein and Fat

	Macronutrient	Gross calorific value Kcal/g	Physiologic Value Kcal/g
1.	Carbohydrate	4.1	4
2.	Protein	5.65	4
3.	Fat	9.45	9

1 Kilocalorie (Kcal) = 1000 calories

Differences between Calorific value and Physiologic value

Calorific value	*Physiologic value*
1. It is the amount of energy produced on complete combustion of 1 gm of food substance in the calorimeter in a laboratory.	1. It is the amount of energy produced on oxidation of 1 gm of food substance in the body.
2. Calorific values of carbohydrates, proteins and fats are 4.1 Kcal/g, 5.65 Kcal/g and 9.45 Kcal/g respectively.	2. Physiologic values of carbohydrates proteins and fats are 4.0 Kcal/g, 4.0 Kcal/g and 9.0 Kcal/g respectively.
3. It is more than physiologic value.	3. It is less than gross calorific value.

Vitamins

N.I. Lunin (1881) discovered vitamins. **Hopkins** and **Funk** (1912) profounded a '**Vitamin Theory**'. Vitamin was chemically an amine and was vital to life. Hence Funk (1911) named it *Vitamine* (*L. vita* – life + amine = vital amine). The term `*vitamin*' is retained now omitting the terminal `e' in its spelling. The book entitled *'The vitamins'* was written by Funk and published in 1922. Vitamins are regarded as organic compounds required in the diet in small amounts to perform specific biological normal maintenance of optimum growth and health of the organisms. The essential chemical components of many coenzymes are vitamins.

Vitamin C is the most sensitive of all vitamins to heat. Antineuritic vitamins are B_1, B_6 and B_{12}. Antioxidant vitamins are A, E and C. Vitamin B_{12} contains cobalt.

Vitamins are divided into two main groups.

Fat soluble vitamins, *e.g.,* vitamins A, D, E and K

Water soluble vitamins, *e.g.,* vitamins B-complex, C and P.

Fat soluble Vitamins

Name	Source	Functions	Deficiency symptoms	Other information
Vitamin A (Retinol)	carrot, tomato, papaya, mango, milk, eggs, cod-liver oil	Essential role for vision, growth, differentiation of epithelial tissue.	Night blindness, Xerophthalmia Abnormal epithelial cell growth	First fat soluble vitamin was discovered by **Mc Collum** (1913). **Paul Karrer** got Nobel Prize (chemistry) in 1937 for determining the structure of carotene and vitamin A.
Vitamin D (Calciferol)	Cod liver oil. Skin can synthesize Vitamin D in the presence of sunlight.	It increases calcium absorption from the gastro-intestinal tract & helps control calcium deposition in the bone	Rickets in children and osteomalacia in adult.	Vitamin D behaves more like a hormone than as the cofactor of an enzyme.
Vitamin E (Tocopherol)	Wheat germ, green leafy vegetables. Fats of vegetable origin,	Acts as good anti-oxidant, essential for normal functioning of reproductive organs, maintains muscles of the body and structure of RBCs.	Reproductive failure (Sterility), muscular dystrophy, increased haemolysis leading to macrocytic anaemia	Vitamin E also called fertility vitamin (vitamin of reproduction) Vitamin E was discoverd by **Herbert Evans & Katherine Bishop** (1922) in green leafy vegetables
Vitamin K There are three derivatives of vitamin K. K_1, K_2 & K_3 **Phylloquinone** (K_1), **Menaquinone** (K_2) and **Menadione** (K_3)	Leafy vegetables, wheat germ, Vitamin K is synthesized by bacteria of large intestine.	It helps in blood clotting, prevention of excessive bleeding.	Faulty blood clotting, Haemorrhage	**Dam** (1939) isolated vitamin K_1 and in the same year **Doisy** isolated vitamin K_2. Both of them shared the 1943 Nobel Prize in Chemistry for chemical nature of Vitamin K.
Water Soluble Vitamins				
B-Complex Vitamin B_1 (Thiamine)	Whole grain wheat germ, legumes, nuts, fish.	Essential for repair and growth of tissues. Helps the body to convert the amino acid tryptophan to niacin. It acts as thiamine pyrophosphate(TPP) in TCA cycle (Krebs Cycle)	**Beri beri** disease (B_1), deficiency in alcoholics causes **Wernicke's syndrome** and **Korsakoff's syndrome**	Alcohol interferes with metabolism of B_1 in the liver. This was discovered by **Eijkman** in 1897.
Vitamin B_2 (Riboflavin)	Milk, cheese, meats, eggs, legumes, wheat germ mushrooms, green leafy vegetables.	It helps in RBCs production. It acts as FMN and FAD. FMN acts in ETC, however FAD acts in both TCA cycle and ETC.	**Cheilosis**	Riboflavin is also called 'yellow enzyme'.

Vitamin B_3 Niacin, Nicotinic acid)	Whole grain nuts, legumes yeast, liver, fish, meat, poultry.	It acts as NAD and NADP in TCA Cycle	**Pellagra**, and **Hartnup disease,** a heriditary abnormality in metabolism of tryptophan.	**Elvehjem** loslated nictotinic acid in 1937.
Vitamin B_5 (Pantothenic Acid)	Yeast, milk, groundnut, tomatoes, liver, meat, wheat germ, honey,egg yolk.	For healthy skin and hair. It forms Coenzyme A in TCA Cycle.	Dermatitis, retarded growth, loss of hair, greying of hair.	Pantothenic acid was first identified by **Williams** and associates in 1933.
Vitamin B_6 (Pyridoxine)	Whole grain, cereals, peanuts, banana, soyabean, meat, vegetables.	Protein metabolism.	**Dermatitis, anaemia,** convulsions, nausea mental disorder, retarted growth.	Discovered by **Albert Szent Gyorgyi** in 1934.
Biotin (Vitamin B_7)	Egg yolk, milk, nuts, honey, liver, meat, fish.	Carbohydrate, protein and fat metabolism.	Poor growth, loss of muscular control, loss of appetite, weakness, hair fall.	Biotin was discovered in 1936 by **Kogl** and **Tonnis.** Raw egg should not be eaten. White of egg contains **avidin** protein which prevents the absorption of biotin. Therefore egg should not be eaten in raw state.
Folic acid (Vitamin B_{10})	Green leafy, vegetables,	Essential for formation of RBCs. Increases appetite	Causes **megaloblastic anaemia or macrocytic anaemia**	Folic acid was discovered by **Lucy Wills** in 1934.
Vitamin B_{12} (Cyanocobalamin, Cobalamin), (Castle's Extrinsic Factor)	It is reported in *Spirulina* (an alga). Animal source Liver, meat, fish, eggs, milk.	RBCs production. DNA Synthesis. Proper functioning of neurological system	**Pernicious anaemia**	**Dorothy Crowfoot Hodgkin** got 1964 Nobel Prize in chemistry for the structure of B_{12}
Vitamin B_{17} (Laetrile)	Wheat grass Juice.	B_{17} has anticancer property.		
Vitamin C (Ascorbic acid)	Citrus fruits amla, guava, tomato.	Essential for the formation of RBCs and the production of antibodies. It is good for bones, teeth and gums. It acts as antioxidant.	Its deficiency causes **Scurvy**	**James Lind** (1753) discovered the cure of scurvy and reported that citrus fruits are rich in vitamin C.
Vitamin P (Hesperidin, citrin).	Citrus fruits, green vegetables.	It maintains wall of blood vessels.		

Differences between Pernicious anaemia and Sickle celled anaemia

Pernicious anaemia	*Sickle celled anaemia*
1. In this disease, there is reduced production of RBCs in bone marrow. 2. It is deficiency disease due to deficiency of vitamin B_{12}. 3. It can be cured by giving vitamin B_{12}.	1. In this disease, there is production of sickle shaped RBCs. 2. It is a hereditary disease due to recessive genes. 3. It is difficult to be cured.

Minerals

Minerals are classified as major and trace. This classification is based on how much of the mineral is needed to the body. **Major minerals (macrominerals)** are important nutrients in our diet. It is suggested that we consume 0.1 gm of each of these minerals per day. **Trace minerals (microminerals)**, as their name indicates, are needed in only small amounts. It is suggested that we consume 0.01 gm of each trace mineral per day.

Macrominerals

Name	Source	Functions	Deficiency Symptoms
Calcium	Dairy products, Eggs, wheat germ,	Useful for formation of bones and teeth, helps in blood clotting, keeps muscles and nerve activity normal.	Rickets and muscle spasms.
Chlorine	Table salt, sea food, chlorinated water.	Maintains *p*H, balance in body fluid, a constituent of hydrochloric acid in stomach.	Disturbs *p*H balance of body fluid.
Magnesium	Dairy products, cereals, green leafy vegetables, sea food, wheat germ, chocolate.	It helps in muscle relaxation & also keeps nerve relaxed, synthesis of bones and teeth.	Convulsions and hallucinations.
Phosphorus/ Phosphate	Dairy products, eggs, fish, meat, wheat germ.	Important for formation of bones, teeth and biomembranes, keeps muscle & nerve activity normal. Synthesis of nucleic acids (DNA, RNA) and synthesis of ATP.	Loss of bone minerals and many many metabolic disorders including cardiac muscle nerves disorders.
Sodium	Table salt, most foods and wheat germ.	It helps in muscle activity and transmission of nerve impulses.	Cramps, diarrhoea and dehydration.
Potassium	Cereals meats, fruits, vegetables.	Needed with sodium, conduction of nerve impulse.	
Sulphur	Dairy products, eggs, meat.	Part of many proteins essential for synthesis of vitamin B_1, for healthy hair, skin, nails,	Interferes with the healthy growth of hair and nails.
Microminerals			
Chromium	Black gram, bajra, barley, groundnuts, meat,	It promotes insulin action. Cardioprotective	Diabetic like symptoms.

Cobalt	Milk, meat	Part of Vitamin B_{12}, therefore, help in the formation of RBCs.	Anaemia
Copper	Pea nuts, barley, black grams	Promotes utilization of iron in haemoglobin.	Anaemia
Flourine	Tea, fish, city water supply.	Prevents dental carries.	Weak teeth, prone to decay.
Iodine	Iodinized salt, sea food.	Constituent of thyroxine hormone, which is secreted by thyroid gland.	Goitre
Iron	Most meats, dried nuts, banana, honey, dates, green leafy vegetables.	Constituent of haemoglobin and myoglobin.	Microcytic Anaemia
Manganese	Nuts, legumes, wheat, germ, liver.	For normal reproduction, function of mammary glands and synthesis of haemoglobin.	Infertility, Menstruation problems, impaired fat metabolism.
Molybdenum	Nuts, wheat, black gram, peas, bajra, potatoes.	Part of several enzymes essential for synthesis of haemoglobin and absorption of iron.	Disturbance in iron metabolism, affects growth of the body.
Selenium	Sea food, meats, cereals.	Part of several enzymes functions with Vitamin E.	Premature ageing cataract, Cancer, Cardiovascular diseases
Zinc	Soyabeans, black gram, wheat germ, barley, bajra, milk, eggs.	A cofactor for many enzymes, such as carbonic anhydrase. Stimulates insulin action, cardioprotective	Poor growth, slow sexual development, impairs wound healing.

Nutritional and Digestive Disorders

1. **Deficiency Diseases.** The important deficiency disorders include **protein energy malnutrition** (PEM) and disorders due to deficiencies of Vitamin A, iron and iodine. Deficiency of protein and energy or both, called PEM, has been identified as major health and nutritional problems in India. Protein and energy intake are difficult to separate because diets adequate in energy are adequate in protein. Young children (0-6 years) require more protein for each kilogram of body weight than adults. So they are more prone to malnutrition. Malnutrition is not only an important cause of childhood mortality and morbidity, but it also leads to permanent impairment of physical and mental growth of those who survive.

(i) **PEM.** It is an important nutritional problem among pre-school children. It leads to various degrees of growth retardation. This is due to lack of adequate quantity of protein or carbohydrate or both.

PEM is of 2 types : **Kwashiorkor** and **Marasmus**.

Deficient Nutrient	Name of Deficiency	Deficiency Symptoms
Protein (PEM)	**Kwashiorkor** (usually observed in children in the age group of 1-5 years)	Weak muscles, thin limbs, retarded growth of body and brain, swelling of legs due to retention of water (oedema), reddish hair, pot belly and diarrhoea.
Protein and Calorie (PEM)	**Marasmus** (it usually affects infants below age of one year).	Impaired growth and replacement of tissue proteins, thin limbs and prominent ribs (very less fat in the body), dry, wrinkled and thin skin, diarrhoea.

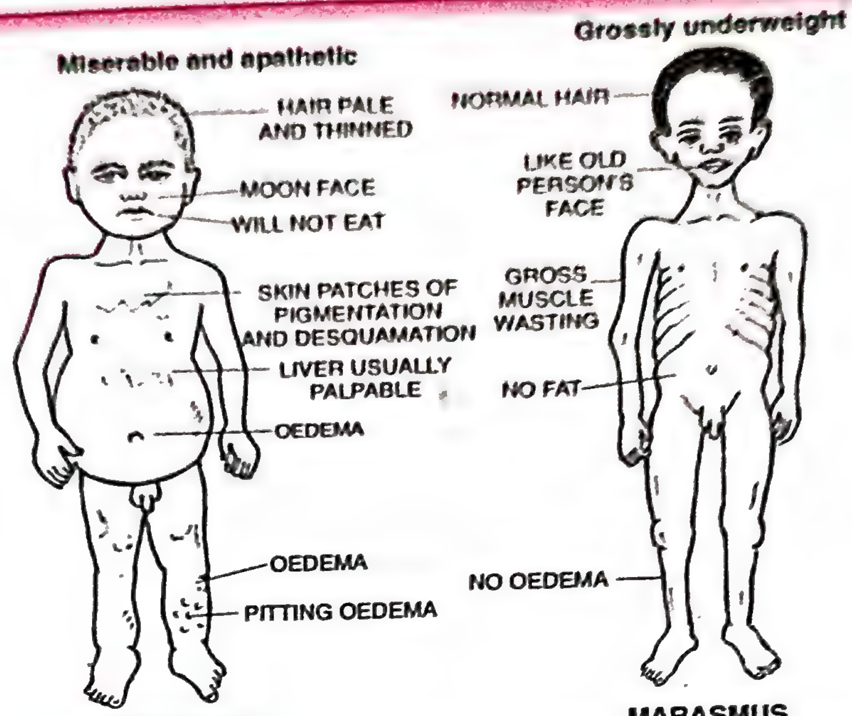


Fig. 16.24. Children suffering from Kwashiorkor and Marasmus.

The child suffering from PEM can recover if adequate quantities of protein and carbohydrate rich food are given.

(ii) **Night blindness and Xerophthalmia.** These diseases are due to deficiency of vitamin A.

(iii) ***Microcytic Anaemia.** This disease is caused by deficiency of iron.

(iv) **Goitre.** Goitre is caused due to deficiency of iodine in food.

In addition to above mentioned deficiency diseases, the following deficiency diseases may be mentioned. Name of deficient is written in the bracket. Rickets in children and osteomalacia in adult (vitamin D), muscular dystrophy (vitamin E), Beri beri (B_1), Cheilosis (B_2), Pellagra (vitamin B_3), Megaloblastic anaemia (Folic acid), Pernicious anaemia (B_{12}), Scurvy (vitamin C).

2. **Indigestion**. Incomplete digestion usually accompanied by one or more of the following **symptoms**— pain, nausea (feeling before vomiting), vomiting, heartburn, acid regurgitation, accumulation of gas and sendout of gas from the stomach.

Hunger (desire for food) and **appetite** (inclination towards food) are extremely important automatic regulatory systems. If they are not maintained they cause indigestion. **Chewing (mastication)**— cutting of food by incisors however, grinding of food by molars. Most of the muscles of chewing are innervated by the motor branch of Vth cranial nerve. The chewing process is controlled by nuclei in the stem brain. **Swallowing (deglutition)** is also important mechanism which has already been described.

Improper chewing and swallowing, inadequate digestive enzymes and gastrointestinal hormones anxiety, over eating, spicy food and high fever cause indigestion of food.

3. **Constipation.** Constipation refers to infrequent or difficult defecation caused by decreased motility of the intestines. Because the faeces remain in the colon for prolonged periods, excessive water absorption occurs, and the faeces become dry and hard. Constipation may be caused by poor habits (delaying defecation), spasms of the colon, insufficient

*Number and size of RBCs and haemoglobin content reduced.

fibre in the diet, inadequate fluid intake, lack of exercise, emotional stress, and certain drugs. A common treatment is a mild laxative, such as milk of magnesia, which induces defecation. However, many physicians maintain that laxatives are habit-forming and that adding fibre to the diet, increasing the amount of exercise and increasing fluid intake are safer ways of controlling this common problem.

4. **Vomiting.** The skeletal muscles of the abdominal wall and diaphragm contract, increasing intra-abdominal pressure, the cardiac sphincter relaxes and the soft palate rises to close off the nasal passages. As a result, the stomach (and perhaps duodenal) contents are forced upward through the oesophagus and pharynx and out the mouth. Excessive vomiting can lead to dehydration. Since a large amount of HCl is lost, the blood becomes alkaline.

This reflex action is controlled by vomit centre in the medulla oblongate of the brain. A feeling of nausea precedes vomiting.

5. **Jaundice.** Jaundice is a yellowish colouration of the sclerae (whites of the eyes), skin and mucous membranes due to a buildup of a yellow compound called bilirubin. After bilirubin is formed from the breakdown of the heme pigment in aged red blood cells, it is transported to the liver, where it is processed and eventually excreted into bile. The three main categories of jaundice are (1) *prehepatic jaundice*, due to excess production of bilirubin; (2) *hepatic jaundice*, due to congenital liver disease — cirrhosis of the liver, or hepatitis; and (3) *extrahepatic jaundic* due to blockage of bile drainage by gallstones or cancer of the bowel or the pancreas.

Because the liver of a newborn functions poorly for a week or so, many babies experience a mild form of jaundice called **neonatal jaundice** that disappears as the liver matures. Usually, it is treated by exposing the infant to blue light which converts bilirubin into substances the kidneys can excrete.

6. **Diarrhoea.** Diarrhoea is an increase in the frequency, volume and fluid content of the faeces caused by increased motility of and decreased absorption by the intestines. When chyme passes too quickly through the small intestine and faeces pass too quickly through the large intestine, there is not enough time for absorption. Frequent diarrhoea can result in dehydration and electrolyte imbalances. Excessive motility may be caused by lactose intolerance, stress, and microbes that irritate the gastrointestinal mucosa.

- **Malnutrition** is a condition caused by not getting enough food or right kind of food. Malnutrition covers problems of both undernutrition and overnutrition. **Undernutrition** is due to unbalanced diet, however, excess intake of food is **overnutrition**.
- **Megaloblastic (= Macroblastic Anaemia).** Presence of large, immature RBCs in blood, impairment of antibody synthesis, caused by deficiency of folic acid.

ADDITIONAL INFORMATION

- The distinguishing characteristic of the pancreatic juice is its high bicarbonate content.
- Saliva excretes morphine, penicillin, streptomycin, urea and mercury. Some other heavy metals such as lead, bismuth, arsenic and drugs like iodides are also excreted in saliva.
- With a normal mixed diet, the stomach completely empties in 3-4 hours.
- **Splanchnology** is the study of the viscera.
- **PCM**— Protein Caloric Malnutrition.
- **World Food Day**— 16th October.
- Cyclostomes and *Labeo* do not have stomach.
- **Hiatal hernia** or **diaphragmatic** is the opening in the diaphragm. The part of the stomach is pushed into the thoracic cavity.
- **Inguinal Hernia**. Abnormal protrusion of abdominal contents (greater omentum and intestine) into the inguinal canal.
- **Inguinal canal** is an oblique passage through the lower part of the anterior abdominal wall and present in both sexes.
- **Cirrhosis of the liver**— The liver appears

orange. It is due to the accumulation of bilirubin in the liver. Other substances are mixed with the yellow pigment (bilirubin), hence the liver appears orange.

- **Itai-Itai.** This disease is caused by cadmium pollution in Japan. It is due to intake of contaminated rice and drinking water. It is characterized by renal tubular damage and osteomalacia.
- Cellulose is not digested in human beings.
- Tapeworms are said to be "Wallowers" because they absorb nourishment through their body surface.
- The **Bursa Fabricius** is a lymphoid tissue, found in the cloaca of birds. Its function is both to protect locally against infection and to produce lymphocytes for the blood stream, hence it has been called a 'cloacal thymus". Like the thymus, it is prominent in young birds and usually much reduced in the adult.
- The adenohypophysis (embryologically it includes anterior lobe and intermediate lobe) of pituitary gland develops as an upward growth (Rathke's pouch) from the ectodermal roof of the stomodaeum (fore gut).
- **Teeth. Homodont**. Similar in shape *e.g.,* fish, amphibians, reptiles, toothed whales, dolphins, porpoises, armadillos. **Heterodont**. Different types of teeth, *e.g.,* few extinct reptiles and most mammals.

Fig. 16.25. Types of teeth based on the attachment.

Acrodont. Teeth attached to the free surface of the jaw bones, *e.g.,* shark, frog, certain reptiles. **Pleurodont**. Teeth attached to the inner side of the jaw, *e.g.,* Salamanders, lizards. **Thecodont**. Teeth embedded in the sockets of the jaw bone *e.g.,* crocodiles, mammals. **Polyphyodont**. Teeth replaced many times during life *e.g.,* fish, frog. **Diphyodont**. Teeth formed twice in life time *e.g.,* most mammals. **Monophyodont**. Teeth formed once in life time *e.g.,* platypus, marsupials, moles, sirenians, toothed whales.

- First permanent teeth to appear are first molars.
- Last permanent teeth to appear are 3rd molars.
- The teeth of the lower jaw usually appear before those of the upper jaw. Teeth in females appear earlier than in males.
- Maximum number of teeth (50) are present in Opossum.
- In frog teeth are only present in the upper jaw. Lower jaw lacks teeth. Two patches of **vomerine teeth** are found on the roof of the buccal cavity. The vomerine teeth kill the prey.
- **Pyorrhoea.** A pus containing discharge from infected gums.
- **Veena Girinath** had performed the first liver transplant in India.
- **Saccharine** has a sweet taste, but it is not a sugar.
- Vitamin E is also called "**beauty vitamin**".
- Unpolished rice contains vitamin B_1. Polished rice contains no vitamin.
- **Dysphagia**— difficulty in swallowing.
- **Dysphasia**— difficulty in speaking.
- The first pancreatic transplant took place in 1966 in the U.S.
- **Halitosis** — bad smell from mouth/bad breath. It is usually due to cavities in the teeth, infection of throat and nose.
- Tea/coffee inhibit the absorption of iron from the diet. Prolonged consumption of tea or coffee after meals can lead to iron deficiency— anaemia.
- The centre in the brain which controls hunger is known as **satiety centre.** It is located in the hypothalamus of the brain.
- In the upper one third of oesophagus only skeletal muscles are found.
- Chief seat of water absorption is small intestine.
- Liver produces proteins like albumin, fibrinogen, prothrombin, but does not produce globulin.
- Gall bladder is absent in adult lamprey (jaw less vertebrate), some seed eating birds (graminivorous such as pigeons), rats, whales, all the perissodactyla (odd toed hoofed mammals, such as horse), and some of artiodactyla (even toed hoofed mammals).
- Peyer's patches are also called '**abdominal tonsils**'.

- **Diastema** is a space in rabbit between the incisors and premolars. It is also a small space between incisors and canines in apes.
- Fibres running between the periodontal membrane to the root of the tooth across the cement are known as **Sharpey's fibres.**
- A 'C' shaped duodenum is a characteristic of man.
- Some people suffer from "travelling sickness" on their way to a hill station in a bus, the sickness comprises nausea and vomiting, which are due to rapidly changing directions of motion of the body stimulating the receptors of the membranous labyrinth, from where the stimuli reach the vomiting centres in the medulla oblongate through the cerebellum.
- During high fever, one does not feel like taking meals because high temperature shuts off the appetite centre.
- **Weber's glands** are present at the border of the tongue on either side posteriorly.
- Bile is alkaiine in man but acidic in cats and dogs.
- Elephant tusks are modified incisors.
- Tusks of Walrus are modified canines.
- Spiny anteaters, scaly anteaters and some whales are toothless.
- "Let your food be your medicine" – Hippocrates.
- **Dental formulae of some Mammals :**

Rabbit	$\frac{2033}{1023} \times 2 = 28$
Dog	$\frac{3142}{3143} \times 2 = 42$
Rat	$\frac{1003}{1003} \times 2 = 16$
Cow, sheep & Goat	$\frac{0033}{3133} \times 2 = 32$
Elephant	$\frac{1003}{0003} \times 2 = 14$
Cat	$\frac{3131}{3121} \times 2 = 30$
Opossum	$\frac{5134}{4134} \times 2 = 50$

- **Ruminant Stomach.** In ruminant animals (mammals that chew the cud) such as cow, buffalos, sheep, goat, camel, deer, etc, the stomach is divided into chambers the **rumen** (paunch), the **reticulum** (honey comb), **omasum** (psalterium) and the **abomasum** (rennet). Camel and deer, however do not have omasum.
- **Pavlove's Pouch.** It is a part of the stomach of dog which is connected with the outside and is used in studies on the gastric section.
- **Nobel Prize Winners who worked on vitamins.** 1. **Eijkman and Hopkins** got 1929 Nobel Prize in physiology or medicine for the discovery of growth stimulating vitamins. 2. **Paul Karrer** succeeded in determining the structure of carotene and vitamin A. He also demonstrated that carotene is converted to vitamin A in the body. For these discoveries Paul Karrer was awarded the Nobel Prize for chemistry in 1937 together with Walter Norman Haworth. 3. **Dam** and **Doisy** got 1943 Nobel Prize in physiology or medicine for chemical nature of vitamin K. 4. **Dorothy Crowfoot Hodgkin** won the 1964 Nobel Prize for chemistry for the analysis of the structure of B_{12}. 5. **George Wald** first elucidated the biochemical function of vitamin A in the process of vision. He got 1967 Nobel Prize in physiology or medicine together with Hartiline and Granit for chemical and physiological visual process in eye.
- **Osmotrophic nutrition.** When the ingested food material is taken by diffusion through body surface, it is called osmotrophic nutrition. Examples : *Trypanosoma*, *Taenia*.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Choose the correct answer among the following :

(a) Gastric Juice Contains
(i) pepsin, lipase and rennin
(ii) trypsin, lipase and rennin
(iii) trypsin, pepsin and lipase
(iv) trypsin, pepsin and rennin

✓ (i)

(b) Succus entericus is the name given to
(i) a junction between ileum and large intestine
(ii) intestinal juice
(iii) swelling in the gut
(iv) appendix

✓ (ii)

2. Match column I with column II

	Column I		*Column II*
(a)	Bilirubin and biliverdin	(i)	Parotid
(b)	Hydrolysis of starch	(ii)	Bile
(c)	Digestion of fat	(iii)	Lipases
(d)	Salivary gland	(iv)	Amylases

✓ (a)— (ii), (b)— (iv), (c) — (iii), (d)— (i)

3. Answer briefly
   (a) Why are villi present in the intestine and not in the stomach ?
   ✓ Villi are present in the intestine to increase the area of intestine so that absorption of digested food occurs efficiently.
   (b) How does pepsinogen change into its active form ?
   ✓ Pepsinogen (inactive form) is first changed by HCl into an active enzyme pepsin. Then, through autocatalysis, more of pepsinogen gets activated to pepsin. Therefore, pepsin hydrolyses the proteins partially to proteoses an dpeptones.
   (c) What are the basic layers of the wall of alimentary canal ?
   ✓ The wall of alimentary canal consists of four main concentric coats. Beginning from outside, these coats are (i) Visceral peritoneum (ii) muscular coat (iii) Sub-mucosa and (iv) mucosa.
   (d) How does the bile help in the digestion of fat ?
   ✓ Refer to the text Function of Bile.
4. Give the dental formula of human beings.
   ✓ Dental formula of human being is $2123/2123 \times 2 = 32$.
5. Describe the digestive role of chymotrypsin. Which two others digestive enzymes of the same category are secreted by its source gland ?
   ✓ Chymotrypsin converts proteins into large peptides. Trypsin and Elastase are two others digestive enzymes of the same category are secreted by its source gland.
6. How are polysaccharides and disaccharides digested ?

✓ **Digestion of Polysaccharids**

Action of Saliva $\text{Starch} \xrightarrow[\text{Amylase}]{\text{Salivary}} \text{Maltose} + \text{Isomaltose} + \alpha\text{-Dextrins}$

Action of Pancreatic Juice

$$\text{Starch} \xrightarrow[\alpha\text{-Amylase}]{\text{Pancreatic}} \text{Maltose} + \text{Isomaltose} + \alpha\text{-Dextrins}$$

Digestion of Disaccharides

Action of Intestinal Juice

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose} + \text{Glucose}$$

$$\text{Isomaltose} \xrightarrow{\text{Isomaltase}} \text{Glucose} + \text{Glucose}$$

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose} + \text{Fructose}$$

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose} + \text{Galactose}$$

$$\text{Dextrins} \xrightarrow{\alpha\text{-Dextrinase}} \text{Glucose}$$

7. What would happen if HCl is not secreted in the stomach ?
   ✓ Pepsinogen (proenzyme) and prorennin (pro-enzyme) will not be converted into pepsin and rennin respectively. HCl provides acidic medium. So, that the enzyme can act on food in stomach. HCl kills bacteria and other harmful organisms that may be present along with food.

8. Explain the term thecodont and diphyodont ?

✓ **Thecodont.** In human beings, teeth are embedded in pits, the sockets of the jaw bones. Such teeth are called thecodont.

Diphyodont. The teeth that appear in two sets, *i.e.*, milk-teeth which are later replaced by permanent teeth. This condition is called diphyodont.

9. Name different types of teeth and their number in an adult human.

✓

	Upper jaw	Lower jaw		Upper jaw	Lower jaw
Incisors	4	4	Premolars	4	4
Canines	2	2	Molars	6	6

10. State the role of pancreatic juice in digestion of proteins.

✓ Refer to the text Digestion of proteins in the small intestine.

11. Describe the process of digestion of protein in stomach.

✓ Refer to the text Digestion of proteins in the stomach.

12. Bile juice contains no digestive enzymes, yet it is important for digestion. Why ?

✓ Refer to the text Functions of bile.

13. How does butter in your food get digested and absorbed in the body ?

✓ Refer to the text Digestion of fats and absorption of fatty acids and glycerols.

14. Dicuss the main steps in the diestion of proteins as the food passes through different parts of the canal.

✓ Refer to the text Digestion of proteins.

15. What are the functions of liver ?

✓ Refer to the text Functions of liver.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Name three accessory digestive organs in human.

✓ Salivary glands, liver and pancreas.

2. At which sites do the proteases act in the small intestine ?

✓ Lumen, surface of microvilli and within mucosal cells.

3. What is the function of bile salts ?

✓ Bile's sodium carbonate neutralises HCl of chyme, its other salts emulsify fats.

4. Name the two parts of the alimentary canal where fat is digested.

✓ Small intestine and stomach.

5. Why are proteases generally released in inactive form ?

✓ In active form, they would hydrolyse the cellular and extracellular proteins of the intestinal wall in the absence of food.

6. Why does a bread piece taste sweeter, when you chew it ?

✓ The starch in the bread is converted into maltose a disacchride, by the action of ptyalin.

7. Mention any two structural features of the small intestine which add to its absorptive capacity.

✓ Presence of villi in the inner surface of small intestine. Presence of microvilli on the free surface of intestinal epithelium.

8. Cite a case of intracellular digestion in humans.

✓ Breakdown of worn-out organelles in cells by lysosomes.

Two Mark Questions (With Answers)

1. Define the term digestion. List the food contents that need digestion.

✓ Change of food incapable of absorption into a form fit for absorption by enzymatic hydrolysis in the gut. Proteins, fats, carbohydrates and nucleic acids need digestion.

2. What is a non-digestive enzyme ? Name such enzyme released into the intestine and give its role.

✓ A non-digestive enzyme does not hydrolyse any compound. Example is enterokinase present in the intestinal juice. It activates trypsinogen to trypsin.

3. What are plicae circulares ? Give their location and function.

✓ Plicae criculares are a series of permanent circular folds on the inner surface of the small intestine, being best developed in the jejunum. They increase absorptive surface.

4. Explain lactose intolerance ?

✓ Lactose intolerance is the inability of some persons digest lactose of the milk due to deficiency or absence of the enzyme lactase. Lactose is fermented by bacteria in their intestine, producing gases and acids. This causes flatulence, cramps, pain and diarrhoea.

Three Mark Questions (Short Answer Type)

1. What is peristalsis ? How does it help in digestion.
2. Mention the processes the food undergoes in the buccal cavity.
3. Mention the digestive glands associated with alimentary canal in man. Which of them produces maximum enzymes and what is their secretion called ?
4. Name the enzymes for protein digestion in the gastric, pancreatic and intestinal juices, the substrate they digest, and the products of their action.
5. Write the role of the following enzymes in the alimentary canal ? (a) Pepsin (b) Carboxypeptidase (c) Rennin (d) Trypsin (e) Chymotrypsin.

Five Mark Questions (Long Answer Type)

1. Describe physiology of digestion of food in human beings.
2. How is the digested fat absorbed ?
3. How does the intestinal juice contribute the digestion of proteins. What provides the alkaline *p*H in the small intestine ?
4. Describe the following processes in the body (a) Coagulation of milk in the alimentary canal. (b) Digestion of fats in the intestine. (c) Digestion of starch in the alimentary canal. (d) Role of bile salts in the digestion and absorption of fats.
5. Discuss the digestion of carbohydrates or proteins in the alimentary canal.

Multiple Choice Questions (With Answers)

(1) Two friends are eating together on a dining table. One of them suddenly starts coughing while swallowing some food. This coughing would have been due to improper movement of
(a) epiglottis (b) diaphragm (c) neck (d) tongue. *(AIPMT (Prelims) 2011)*

(2) Which one of the following enzymes carries out the initial step in the digestion of milk in humans?
(a) Pepsin (b) Rennin (c) Lipase (d) Trypsin. *(AIPMT (Prelims) 2011)*

3) One of the constituents of the pancreatic juice which is poured into the duodenum in humans is
(a) trypsinogen (b) chymotrpsin (c) trypsin (d) enterokinase. *(AIPMT (Mains) 2011)*

(4) Which one of the following correctly represents the normal adult human dental formula ?
(a) $\frac{3}{3},\frac{1}{1},\frac{3}{2},\frac{1}{1}$ (b) $\frac{2}{2},\frac{1}{1},\frac{3}{2},\frac{3}{3}$, (c) $\frac{2}{2},\frac{1}{1},\frac{2}{2},\frac{3}{3}$ (d) $\frac{3}{3},\frac{1}{1},\frac{3}{3},\frac{3}{3}$ *(AIPMT (Mains) 2011)*

(5) The 2005 Noble Prize for Physiology Medicine was awarded to Barry Marshall and Robin Warren of Australia for their discovery of (a) human papilloma virus causing cervical cancer (b) bacterium *Helicobacter pylori* causing peptic ulcer (c) prions, a new biological principle of infection (d) human immunodeficiency virus. *(Karnataka CET 2011)*

(6) A balanced diet does not include (a) carbohydrates and fats (b) nucleic acids and enzymes (c) proteins and vitamins (d) minerals and salts. *(Karnataka CET 2011)*

(7) Kupffer's cells are (a) phagocytic (b) mast cells (c) hormone secreting (d) digestive juice secreting. *(West Bengal JEE 2011)*

(8) Anxiety and eating spicy food together in an otherwise normal human may lead to
(a) indigestion (b) jaundice (c) diarrhoea (d) vomiting. *(CBSE Prelims 2012)*

(9) Where do certain symbiotic microorganisms normally occur in human body ?
(a) Caecum (b) Oral lining and tongue surface (c) Vermiform appendix and rectum (d) Duodenum *(CBSE PMT Main 2012)*

(10) For its activity, carboxypeptidase requires
(a) zinc (b) iron (c) niacin (d) copper *(CBSE PMT Main 2012)*

(11) The common passage for bile and pancreatic juice is (a) ampulla of vater (b) ductus choledochus (c) duct of Warsung (d) duct of Santorini. *(AMU 2012)*

(12) The falciform ligament in man connects (a) liver with diaphragm (b) lungs with diaphragm (c) stomach with diaphragm (d) liver with stomach. *(AMU 2012)*

*(13) In human beings, the three pair of salivary glands and numerous buccal glands produce about. (a) 1.0 dm^3 of saliva per day (b) 1.5 dm^3 of saliva per day (c) 2.0 dm^3 of saliva per day (d) 2.5 dm^3 of saliva per day. *(AMU 2012)*

(14) In the gastrointestinal tract, the Meissner's plexus and the Auerbach's plexus occur respectively in the (a) lamina propria and muscularis mucosa (b) submucosa and muscularis externa (c) submucosa and mucosa (d) mucosa and muscularis externa. *(AMU 2012)*

(15) Which of the following is a mixed gland ?
(a) Thyroid gland (b) Adrenal gland (c) Pituitary gland (d) Pancreas. *(Odisha JEE 2012)*

(16) Main function of HCl present in gastric juice is (a) digestion of starch (b) emulsification of fat (c) conversion of pepsinogen to pepsin (d) detoxification of harmful constituents of food. *(Odisha JEE 2012)*

(17) Most of the hydrolytic enzymes of lysosome function at (a) acidic *p*H (b) alkaline *p*H (c) neutral *p*H (d) both (b) and (c). *(Odish JEE 2012)*

(18) Brunner's gland is present in (a) duodenum (b) jejunum (c) ileum (d) rectum. *(West Bengal JEE 2012)*

(19) Higher animals cannot synthesize few fatty acids which are very essential for their growth and development. These fatty acids are typically (a) saturated (b) cyclic (c) unsaturated (d) branched. *(West Bengal JEE 2012)*

(20) The semi-digested food that moves down the oesophagus is known as (a) bolus (b) chyme (c) rugae (d) protein. *(Karnataka CET 2013)*

(21) Ileocaecal valve is present in between (a) colon and large intestine (b) colon and small intestine (c) stomach and small intestine (d) cardiac, stomach and fundus. *(Karnataka CET 2013)*

(22) Which of the following is a protein deficiency disease ? (a) Osteomalacia (b) Kwashiorkor (c) Pellagra (d) Rickets. *(AMU Med. 2013)*

(23) After surgical removal of an infected gall bladder, a person must be especially careful to restrict dietary intake of (a) starch (b) protein (c) sugar (d) fat. *(AMU Med. 2013)*

(24) The essential chemical components of many coenzymes are (a) proteins (b) nucleic acids (c) carbohydrates (d) vitamins. *(NEET 2013)*

(25) Select the correct match of the digested products in humans given in column I with their absorption site and mechanism in column II.

Column I	Column II
(1) Glycine, glucose	Small intestine, active absorption
(2) Fructose, Na^+	Small intestine, passive absorption
(3) Glycerol, fatty acids	Duodenum, move as chilomicrons
(4) Cholesterol, maltose	Large intestine, active absorption

(NEET 2013)

(26) In which one of the following, expenditure of energy is required? (a) Osmosis (b) Diffusion (c) Active transport (d) Passive transport. *(WB JEE 2014)*

(27) the salivary amylase shows maximum digestive action at *p*H ________. (a) 3.6 (b) 6.8 (c) 7.5 (d) 8.5. *(Maharashtra CET 2014)*

(28) Fish proteins are considered nutritionally superior to most vegetable proteins because they are rich in (a) all the 20 amino acids (b) essential amino acids (c) peptide bonds (d) polypeptides. *(AMU 2014)*

(29) Coenzymes NAD and NADP contain the vitamins
(a) niacin (b) biotin (c) thiamine (d) vitamin B_{12} (e) vitamin A. *(Kerala PMT 2014)*

(30) Fructose is absorbed into the blood through mucosa cells of intestine by the process called (a) active transport (b) facilitated transport (c) simple diffusion (d) co-transport mechanism. *(AIPMT 2014)*

(31) The primary dentition in human differs from permanent dentition in not having one of the following type of teeth (a) canine (b) premolars (c) molars (d) incisors. *(CBSE 2015)*

(32) The enzyme that is not present in succus entericus is
(a) maltase (b) nucleases (c) nucleosidase (d) lipase. *(CBSE 2015)*

(33) Emulsification of fat occurs by (a) bile salts (b) bile pigments (c) pancreatic juice (d) succus entericus. *(J&KCET 2015)*

*13. If 1500 ml of saliva is secreted, daily by a human, it is equivalent to 1.5 dm^3 (dm - decimetre).

(34) Which of the following guards the opening of hepatopancreatic duct into the duodenum ?
(a) Ileocaecal valve (b) Pyloric sphincter (c) Sphincter of Oddi (d) Semilunar valve. *(NEET-I-2016)*

(35) In the stomach, gastric acid is secreted by the
(a) parietal cells (b) peptic cells (c) acidic cells (d) gastrin secreting cells. *(NEET-I-2016)*

(36) Which hormones do stimulate the production of pancreatic juice and bicarbonate ?
(a) Angiotensin and epinephrine (b) Gastrin and insulin (c) Cholecystokinin and secretin (d) Insulin and glucagon. *(NEET-II-2016)*

(37) Name a peptide hormone which acts mainly on hepatocytes, adipocytes and enhances cellular glucose uptake and utilisation. (a) insulin (b) glucagon (c) secretin (d) gastrin. *(NEET-II-2016)*

(38) Which cells of 'crypts of Lieberkuhn' secrete antibacterial lysozyme ? (a) Paneth cells (b) Zymogen cells (c) Kupffer cells (d) Argentaffin cells. *(NEET 2017)*

(39) A baby boy aged two years is admitted to play school and passes through a dental check-up. The dentist observed that the boy had twenty teeth. Which teeth were absent ? (a) Canines (b) Pre-molars (c) Molars (d) Incisors. *(NEET 2017)*

(40) Which of the following options best represents the enzyme composition of pancreatic juice ?
(a) Amylase, Pepsin, Trypsinogen, Maltase (b) Peptidase, Amylase, Pepsin, Rennin (c) Lipase, Amylase, Trypsinogen, Procarboxypeptidase (d) Amylase, Peptidase, Trypsinogen, Rennin. *(NEET 2017)*

Assertion and Reasion Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as :
*(a) If both **A** and **R** are true and **R** is the correct explanation of **A***
*(b) If both **A** and **R** are ture and **R** is not the correct explanation of **A***
*(c) If **A** is true but **R** is false*
*(d) If both **A** and **R** are false.*

(1) **Assertion :** Bile is not a true digestive juice.
Reason : Bile lacks digestive enzymes.
(A) (B) (C) (D)

(2) **Assertion :** The main part of carbohydrate digestion takes palce in small intestine.
Reason : Here pancreatic amylase converts carbohydrates into lactose.
(A) (B) (C) (D)

(3) **Assertion :** Strach is hydrolysed by ptyalin to maltose.
Reason : Sucrose hydrolyses sucrose to lactose.
(A) (B) (C) (D) *(AIIMS 2001)*

(4) **Assertion :** Hydrochloric acid does not digest the stomach wall.
Reason : Hydrochloric acid is unable to denature the proteins.
(A) (B) (C) (D)

ANSWERS

Multiple Choice Questions

(1) —a (2) —a (3) —a (4) —c (5) —b (6) —b (7) —a (8) —a (9) —a (10) —a
(11) —a (12) —a (13) —b (14) —b (15) —d (16) —c (17) —a (18) —a (19) —c (20) —a
(21) —b (22) —b (23) —d (24) —d (25) —a (26) —c (27) —b (28)—a (29) —b (30) —b
(31) —b (32) —b (33) —a (34) —c (35) —a (36) —c (37) —a (38) —a (39) —b (40) —c

Assertion and Reason type Questions

(1) —A (2) —C (3) —C (4) —C

Chapter 17

Breathing and Exchange of Gases

THEORY– a quick rundown

Breathing

It involves inspiration and expiration. During **inspiration** air enters the lungs from atmosphere and during **expiration** air leaves the lungs. During normal breathing, inspiration is the active process and expiration is a passive process.

What is Respiration ?

Respiration is an oxidation process involving the burning up of food substances such as carbohydrates, fats and proteins within the tissues to form carbon dioxide, water and consequent release of energy. The released energy is temporarily stored as ATP.

Respiratory Organs/Structures

- **Respiratory Structures for exchange of gases in different animal groups**

	Animal Groups	Respiratory Device
1.	**Protozoa** (*e.g., Amoeba, Paramecium*)	Plasmalemma, Pellicle
2.	**Porifera** (*e.g., Sycon*)	Plasma membrane of each cell
3.	**Cnidaria** (*e.g., Hydra*)	Body wall
4.	**Ctenophora** (Comb Jellies, *e.g., Hormiphora*)	Body wall
5.	**Platyhelminthes**	
	(i) Free living (*e.g., Planaria*)	Body surface
	(ii) Parasites (*e.g.,* Liverfluke, Tapeworm)	Anaerobic Respiration (No exchange of gases)
6.	**Nemathelminthes**	
	(i) Free living (*e.g., Rhabditis*)	Body surface
	(ii) Parasites (*e.g., Ascaris*)	Anaerobic Respiration (No exchange of gases)
7.	**Annelids** *e.g., Nereis*, Earthworm, Leech	Body wall (Cutaneous Respiration)
	Arenicola, Amphitrite, Terebella	Body wall, gills

8. **Arthropoda**	
(a) Crayfish, Prawn	Gills (Branchial respiration)
(b) Insects, Centipedes, Millipedes, Ticks, *Peripatus*	Tracheae (Tracheal Respiration)
(c) Scorpions, Spiders	Book lungs
(d) Mites	Cutaneous respiration
(e) *Limulus* (King crab)	Book gills
9. **Mollusca** (*e.g.*, *Unio*, *Pila*)	Two ctenidia (gills) in Unio, one ctenidium (gill) and one pulmonary sac ('lung') in *Pila*
10. **Echinodermata** (*e.g.*, *Starfish*)	Dermal branchae, Tube feet
11. **Hemichordata** (*e.g.*, *Balanoglossus*)	Pharyngeal wall
12. **Chordata**	
(i) **Urochordata** (*e.g.*, *Herdmania*)	Pharyngeal wall
(ii) **Cephalochordata** (*e.g.*, *Branchiostomata*)	Pharyngeal wall
(iii) **Vertebrata**	
(a) Cyclostomes, Fishes	Gills
(b) Amphibians (*e.g.*, Frog)	Skin, Buccopharyngeal cavity, lungs
(c) Reptiles, Birds, Mammals	Lungs

Human Respiratory System

1. **Nostrils (External Nares).** A pair of holes of the nose are called nostrils.

2. **Nasal Cavities.** Two nasal cavities are separated by a **nasal septum**. Three bony ridges the **superior, middle** and **inferior nasal conchae** arise from the wall of each nasal cavity.

3. **Internal Nares.** These are paired openings which open into the pharynx.

4. **Pharynx.** It provides passage to both air and food. It comprises **nasopharynx, oropharynx** and **laryngopharynx**.

5. **Larynx (Sound Box).** It is prominent in man where it is called **Adam's apple.** Some scientists consider thyroid cartilage as Adam's apple. The pharynx opens into the larynx by an aperture, the **glottis**. There are nine pieces of cartilages. Three are single and three are paired. (a) **Epiglottis—** one, made up of cartilage (b) **Thyroid cartilage–** One, made up of hyaline cartilage, is the largest cartilage of the larynx. (c) **Cricoid cartilage–** one like a ring, made up of hyaline cartilage. (d) **Arytenoid cartilages–** one pair, made up of hyaline and elastic cartilages. (e) **Cartilages of Santorini** – one pair, made up of elastic large cartilage. (f) **cueiform cartilages** – one pair, made up of elastic cartilage. **Hyoid bone** – lies just above the larynx. Embryologically it is considered a bone of skull. **Vocal cords** – two pairs; one pair **false vocal cords** and one pair **true vocal cords**. The **rima glottidis** is a gap between the vocal cords that communicates with the laryngopharynx above. Sound is produced by true vocal cords.

6. **Trachea and Primary Bronchi.** The larynx leads into the **trachea**. Its rings are made up hyaline cartilage. The rings of trachea (wind pipe) are incomplete posteriorly. The trachea is lined by pseudostratified ciliated columnar epithelium. Trachea is straight tube and extends up to the mid-thoracic cavity.

The trachea divides at the level of 5th thoracic vertebra into a right and left **primary bronchi**. The walls of the bronchi are also supported by cartilaginous rings. The primary bronchi enter the right and left lungs.

7. **Lungs (= Pulmones).** Each lung is enclosed by two membranes: outer **parietal pleuron** and inner **visceral pleuron** with a **pleural cavity** in between two pleura. The cavity is filled with **pleural fluid** secreted by the pleura.

The left lung is smaller than the right lung. The left lung has a concavity, the **cardiac notch,** where the heart lies. The left lung has two lobes, however, right lung has three lobes.

(a) As soon as the primary bronchus enters each lung it divides to form **secondary** and **tertiary bronchi**. (b) The tertiary bronchi sub-divide into smaller branches, the **bronchioles** which are without cartilaginous rings. After repeated branching, one of the smaller bronchioles enter a lung lobule called **lobular bronchiole**. The latter gives rise to about six **terminal bronchioles** which further subdivide into **respiratory bronchioles.** (c) The respiratory bronchioles open into two or three **alveolar ducts** which terminate in expanded passage, the **atria**, (sing atrium) which in turn lead into **alveolar sacs** or air sacs. The latter open into several **alveoli** (also called **acini**). The alveoli have very thin wall consisting of squamous epithelium. Due to very intimate contact of blood capillaries with the alveoli, the exchange of gases takes place easily. Thus each alveolus may be called a miniature lung where exchange of gases takes place.

Respiration involves the following steps :

(i) Breathing is the inflow (**inspiration**) and outflow (**expiration**) of air between atmosphere and the alveoli of the lungs.

(ii) Diffusion of gases (O_2 and CO_2) across alveolar membrane.

(iii) Transport of gases by the blood.

(iv) Diffusion of O_2 and CO_2 between the blood and the tissues.

(v) Utilisation of O_2 by the cells for catabolic reactions and resultant release of CO_2 (cellular respiration) described in the chapter 14.

Mechanism of Breathing

It involves inspiration and expiration.

1. **Inspiration.** It is a process by which fresh air enters the lungs. The diaphragm, intercostal muscles and abdominal muscles play an important role.

(i) **Diaphragm.** The diaphragm becomes flat and gets lowered by the contraction of its muscle fibres thereby increasing the volume of the thoracic cavity in length.

(ii) **External intercostal muscles.** They occur between the ribs. These mucles contract and pull the ribs and sternum upward and outward thus increasing the volume of the throacic cavity.

(iii) **Abdominal Muscles.** These muscles relax and allow compression of abdominal organs by the diaphragm. Abdominal muscles play a passive role in inspiration.

The muscles of the diaphragm and external intercostal muscles are **principal muscles of inspiration.**

Movement of Fresh Air into the Lungs. Thus overall volume of the thoracic cavity increases and as a result there is a decrease of the air pressure in the lungs. The greater pressure outside the body now causes air to flow rapidly into external nares (nostrils) and through nasal chambers into internal nares. Thereafter the sequence of air flow is like this:- External nares → Nasal cavaties → Internal nares → Pharynx → Glottis → Larynx → trachea → Bronchi → bronchioles → alveolar ducts → alveoli.

2. **Expiration.** It is a process by which the foul air (carbon dioxide) is expelled out from the lungs. Expiration is a passive process which occurs as follows.

(i) **Diaphragm.** The muscle fibres of the diaphragm relax making it convex, decreasing volume of the thoracic cavity.

(ii) **Internal Intercostal muscles.** These muscles contract so that they pull the ribs downward and inward the lower ribs thereby decreasing the size of the thoracic cavity.

(iii) Abdominal muscles. Contraction of the abdominal muscles such as **external** and **internal oblique muscles** compresses the abdomen and pushes its contents (viscera) towards the diaphragm.

The internal intercostal and abdominal muscles are **muscles of expiration.**

Movement of Foul Air out of the lungs. Thus overall volume of the thoracic cavity decreases and foul air goes outside from the cavaties of the alveoli in the following manner:- Alveoli → alveolar ducts → bronchioles → bronchi → trachea → larynx → glottis → pharynx → internal nares → nasal cavaties → external nares → outside.

On an average, a healthy person breathes 12–16 times/minute. The volume of air involved in breathing movements can be estimated by a **Spirometer** which helps in clinical assessment of pulmonary functions.

Advantages of Nasal Breathing

Breathing through nose is healthier because it is a natural process. The air which is inhaled contains dust, bacteria, etc . get filtered in the nose. Thus the air which goes into lungs is cleaner. The conchae of the nose also filter and warm up the air.

- At rest, breathing occurs about 14-18 times per minute in a normal man, being more in children.
- Mammals have **negative pressure breathing** as it allows them to eat and breathe at the same time.
- In human female, thoracic breathing is more predominant.

Respiratory Volumes and Capacities

Respiratory Volumes. In breathing, the lungs are neither completely filled with air nor completely emptied. Recording the volume movement of air into and out of the lungs is called **spirometry.** It is done with the help of a **spirometer**. Generally, the air in the lungs is divided into four different 'respiratory volumes' in man.

1. Tidal Volume(TV). It is the volume of air inspired or expired with each normal breath. Normal value 500 ml (0.5 litre).

2. Inspiratory Reserve Volume (IRV). It is the extra amount of air that can be inspired forcibly after a normal inspiration. It is about 2500 to 3000 ml.

3. Expiratory Reserve Volume (ERV). It is the extra amount of air that can be expired forcibly after a normal expiration. It is about 1000 ml to 1100 ml.

4. Residual Volume (RV). It is the volume of air which remains still in the lung after the most forceful expiration. It is about 1100 ml to 1200 ml.

Pulmonary Capacities. Combinations of two or more 'respiratory volumes' are called 'pulmonary capacities'.

1. Vital Capacity (VC). It is the amount of air which can be maximum inspired and also maximum expired. It is equal to sum of tidal volume, inspiratory reserve volume and expiratory reserve volume (VC =TV +IRV +ERV). The vital capacity is higher in athletes, mountain dwellers than in plain dwellers, in men than women and in the young ones than in the old persons.

2. Inspiratory Capacity (IC). It is the total volume of air that can be inhaled after a normal exhalation. It includes tidal volume plus the inspiratory reserve volume (TV + 1RV).

3. Expiratory Capacity (EC). Total volume of air a person can expire after a normal expiration. This includes tidal volume and expiratory reserve volume (TV + ERV).

4. Functional Residual Capacity (FRC). It is the sum of expiratory reserve volume and residual volume (ERV + RV).

5. **Total Lung Capacity (T.L.C).** Vital capacity plus residual volume (VC + RV) make the total lung capacity. It mains it includes RV, ERV, TV and IRV.

Respiratory Quotient (RQ)

Respiratory quotient is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed over a period of time in respiration.

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ absorbed}}$$

Respiratory quotient varies with different foods utilized in respiration. For glucose, RQ is 1 ($RQ = 6CO_2/6O_2 = 1$), for fats it is about 0.7, for proteins it is about 0.9 and for organic acids it is about 1.3 or 1.4. In anaerobic respiration, there is no consumption of oxygen. Carbon dioxide is produced in most of the cases. Therefore, R.Q. is inifinity. The respiratory quotient indicates the type of food oxidized in the body of the animal during respiration.

R.Q. is determined by **Ganong's respirometer.**

Artificial Respiration

Persons who have stopped breathing because of drowning, electric shocks, or smoke inhalation may be subjected to artificial breathing until their own breathing can be initiated. A variety of methods of artificial respiration have been practiced over the years, but the **mouth to mouth breathing method** is very common.

Functions of Respiration

(1) **Energy production.** All living beings require energy to carry out various activities of the body, its parts and cells. The energy required for daily metabolic activities is derived from the oxidation of food going on continuously in the body. (2) **Excretion.** Respiration excretes carbon dioxide, water, etc. (3) **Maintenance of acid-base balance.** Elimination of CO_2 maintains the acid-base balance in the body. (4) **Maintenance of temperature.** A large amount of heat is expelled out during expiration which maintains the body temperature. (5) **Return of blood and lymph.** During inspiration the intraabdominal pressure increases and the intrathoracic pressure decreases. This results the return of blood and lymph from the abdomen to the thorax.

Exchange of Gases

The air reaches the alveoli of the lungs during the inspiration. The atmospheric air contains

Oxygen	20.9 per cent	Carbon dioxide	0.04 per cent
Nitrogen and other inert gases	79 per cent	Water Vapour	Variable.

(i) Gases always diffuse from an area of higher concentration to the area of lower concentration.

(ii) Gases always exert pressure upon all the walls of their container and fill their container completely.

(iii) The molecules of gases are always in motion.

During respiration the lungs and the respiratory tract are never empty of air. Instead, there is a **tidal volume of air** (about 500 ml).

The respiratory gases such as oxygen and carbon dioxide move freely by the process of diffusion. The process of diffusion is directly proportional to the pressure caused by the gas alone. The pressure exerted by an individual gas is called **partial pressure.** It is represented as PO_2, PCO_2, PN_2 for oxygen, carbon dioxide and nitrogen respectively.

Partial Pressure (in mm Hg) of Respiratory Gases

Respiratory Gas	*Atmospheric air*	*Alveolar airblood*	*Deoxygenated blood*	*Oxygenated*	*Tissues*
Oxygen	159	104	40	95	40
Carbon dioxide	0.3	40	45	40	45

Exchange of gases occurs in lungs and the body tissues.

(A) **Exchange of Gases in Lungs.** The pulmonary arteries carry deoxygenated blood to the lungs and the pulmonary veins carry oxygenated blood from the lungs. In the lungs, exchange of gases takes place between alveoli and blood capillaries. This is called **external respiration**.

The partial pressur of oxygen (PO_2) in the alveoli is higher (104 mmHg) than that in the deoxygenated blood in the capillaries of the pulmonary arteries (40 mmHg). As the gases diffuse from a higher to a lower concentration, the movement of oxygen is from the alveoli to the blood. The reverse is the case in relation to carbon dioxide. The partial pressure of carbon dioxide (PCo_2) is higher in deoxygenated blood (45 mmHg) than in alveoli (40 mmHg). Therefore carbon dioxide passes from the blood to the alveoli.

Oxygen-Haemoglobin Curve

The relationship between the partial pressure of oxygen (PO_2) and percentage saturation of haemoglobin with oxygen (O_2) is graphically illustrated by a curve called **oxygen haemoglobin dissociation curve**. Under normal conditions, the oxygen haemoglobin dissociation curve is sigmoid shaped or 'S' shaped.

Factors affecting oxygen Haemoglobin dissociation curve. The oxygen haemoglobin dissociation curve is shifted either to right or left by various factors.

Shift to right. (i) Decrease in partial pressure of oxygen. (ii) *Increase in partial pressure of carbon dioxide (Bohr effect).* (iii) Decrease in *p*H (acidity). (iv) Increase in body temperature.

Shift to left. (i) In the foetal blood, foetal haemoglobin has more affinity. (ii) Low temperature. (iii) High *p*H (alkaline).

***Bohr effect.** In regions with an increased partial pressure of carbon dioxide, the oxygen haemoglobin dissociation curve is shifted to the right. This is known as the **Bohr effect**. It is due to a change in the binding affinity of oxygen to haemoglobin.

Factors Influencing Bohr Effect. All the factors, which shift the oxygen haemoglobin dissociation curve to the right (mentioned above) increase the Bohr effect.

(B) **Exchange of Gases in Tissues.** The oxygenated blood is sent from the blood capillaries to the heart. The heart distributes this oxygenated blood to various body parts through arteries. The arteries divide to from arterioles. The latter further divide to form capillaries. The exchange of oxygen and carbon dioxide between tissue blood capillaries and tissue cells takes place which is also called **internal respiration**. The partial pressure of oxygen is higher (95mm Hg) than that of the body cells (20 mm Hg) and the partial pressure of carbon dioxide is lesser (46 mm Hg) than that of the body cells (52 mm Hg). Therefore, oxygen diffuses from the capillary blood to the body cells through tissue fluid and carbon dioxide diffuses from the body cells of the capillary blood via tissue fluid. Now the blood becomes deoxgenated. The latter is carried to the heart and hence to the lungs.

Transport of Gases

Blood carries oxygen from the lungs to the heart and from the heart to various body parts. The blood also brings carbon dioxide from the body parts to the heart and then to the lungs.

*Christian Bohr

A. Transport of Oxygen

(i) **As dissolved gas.** About 3 per cent of oxygen in the blood is dissolved in the **plasma** which carries oxygen to the body cells.

(ii) **As oxyhaemoglobin.** About 97% of oxygen is carried in combination with **haemoglobin** of the erythrocytes. Oxygen and haemoglobin combine in an easily reversible reaction to form **oxyhaemoglobin.**

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{Oxygen}}{O_2} \underset{\text{Dissociation of } O_2 \text{ In tissues}}{\overset{\text{Binding of } O_2 \text{ In lungs}}{\rightleftharpoons}} \underset{\text{Oxyhaemoglobin}}{HbO_2}$$

B. Transport of Carbon dioxide.

In the oxidation of food, carbon dioxide, water and energy are produced. Carbon dioxide in gaseous form diffuses out of the cells into the capillaries, where it is transported in three ways.

(i) **As dissolved gas.** Because of its high solubility, about 7 percent carbon dioxide gets dissolved in the blood plasma and is carried in solution form to the lungs.

(ii) **As bicarbonate ions.** The dissolved carbon dioxide in the blood reacts with water to from carbonic acid. This reaction is very slow in blood plasma, but occurs very rapidly inside RBCs because a zinc–containing enzyme, the **carbonic anhydrase**, present in RBCs, accelerates its rate about 5000 times. Due to this, about 70% of CO_2 (about 2.5 ml per 100 ml of blood), received by blood from the tissues, enters the RBCs where it reacts with water to form **carbonic acid** ($H_2\,CO_3$).

Almost as rapidly as formed, all carbonic acid of RBCs dissociates in hydrogen (H^+) and bicarbonate ions ($H_2\,CO_3^-$).

$$CO_2 + H_2O \xrightleftharpoons{\text{Carbonic anhydrase}} \underset{\text{Carbonic acid}}{H_2\,CO_3} \rightleftharpoons \underset{\text{Hydrogen}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

Most of the hydrogen ions then combine with the haemoglobin in the RBCs because haemoglobin is a powerful acid-base buffer. In turn, many of the bicarbonate ions diffuse into the blood plasma while chloride ions diffuse into the RBCs. This is made possible by the presence of a special **bicrbonate –chloride carrier protein** in the RBC membrane that moves their two ions in opposite directions at rapid velocites. Thus, the chloride content of venous (deoxygenated) RBCs is greater than that of arterial (oxygenated) RBCs.

Chloride shift (= Hamburger's phenomenon).

Exit of bicarbonate ions, considerably change ionic balance between the plasma and the erythrocytes (RBCs). To restore this ionic balance, **the chloride ions diffuse from the plasma into the erythrocytes**. This movement of chloride ions is called **chloride shift** (= Hamburger's phenomenon). The latter maintains an acid-base equilibrium of *p*H 7.4 for the blood and electrochemical balance between erythrocytes and plasma. The chloride ions (Cl^-) inside RBC combine with potassium ion (K^+) to form potassium chloride (KCl), whereas bicarbonate ions (HCO_3) in the blood plasma combine with Na^+ to form sodium bicarbonate ($NaHCO^-{}_3$).

$$KHbO_2 + H^+ \underset{\text{Erythrocyte}}{\rightleftharpoons} H\,.\,Hb + K + O_2$$

$$K^+ + Cl^- \underset{\text{Erythrocyte}}{\rightleftharpoons} KCl$$

$$Na^+ + HCO_3^- \underset{\text{Plasma}}{\rightleftharpoons} NaHCO_3$$

(iii) **As carbaminoheamoglobin.** In addition to reacting with water, carbon dioxide also reacts directly with amino radicals (NH_2) of haemoglobin to form an unstable compound **carbaminohaemoglobin** (CO_2 HHb, also written $HbCO_2$). This is reversible reaction. A small amount of carbon dioxide also reacts in the same way with the plasma proteins. About 23 percent CO_2 is transported in combination with haemoglobin and plasma proteins.

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{Carbon dioxide}}{CO_2} \rightleftharpoons \underset{\text{Carbaminohaemoglobin}}{Hb - CO_2}$$

Release of Carbon dioxide in the Alveoli of Lung. The pulmonary arteries carry deoxygenaed blood to the lungs. This blood contains carbon dioxide as dissolved in blood plasma, as bicarbonate ions and as carbominohaemoglobin.

(i) CO_2 is less soluble in arterial blood than in venous blood. Therefore, some CO_2 diffuses from the blood plasma of the lung capillaries into the lung alveoli.

(ii) For the release of CO_2 from the biocarbonate a series of reverse reactions takes place. When the haemoglobin of the lung blood capillaries takes up O_2, the H^+ is released from it. Then, the Cl^- and HCO_3^- ions are released from KCl blood, and $NaHCO_3$ in the RBC respectively. After this HCO_3^- reacts with H^+ to form H_2CO_3. As a result H_2CO_3 splits into carbon dioxide and water in the presence of carbonic anhydrase enzyme and CO_2 is released into the alveoli of the lungs.

(iii) High PO_2 in the lung blood capillaries due to oxygenation of haemoglobin favours separation of CO_2 from carbaminohaemoglobin.

Haldane Effect

The amount of CO_2 that can be transported in the blood is influenced by the percent saturation of haemoglobin with oxygen. The lower the amount of oxyhaemoglobin ($Hb - CO_2$), the higher the CO_2 carrying capacity of the blood. This relationship is known as Haldane effect (J. S. Haldane). In brief Haldane effect can be defined— as pH of blood decreases (oxyhaemoglobin is acidic) more and more CO_2 is released.

Causes for Haldane Effectt. Due to the combination with oxygen, the haemoglobin becomes strongly acidic. The highly acidic haemoglobin has less tendency to combine with carbon dioxide. Because of the acidity hydrogen ions are released in excess. The hydrogen ions bind with bicarbonate ions to form carbonic acid. Carbonic acid in turn dissociates into water and carbon dioxide. The carbon dioxide is released from blood into alveoli.

Significance ofHaldane Effect. Haldane effect plays far important role in promoting carbon dioxide transport than is the Bohr effect in promoting oxygen transport.

Regulation of Respiration

Respiration is under both neural and chemical regulation.

1. **Neural Regulation of Respiration.** Normal quiet breathing occurs involuntarily. Adult human beings breathe 12 to 16 times per minute, but human infants breathe about 44 times per minute. In each breath in human beings, inspiration accounts for about two and expiration for about three seconds.

The '**respiratory centre**' is composed of *groups of neurons* located in the medulla oblongata and pons varolii. The respiratory centre regulates the rate and the depth of the breathing. The respiratory centre is divided into three major collections of neurons.

(i) **Dorsal Respiratory Group.** It is located in dorsal portion of the medulla oblongata. Nerve impulses from the dorsal respiratory group stimulate the muscles of the diaphragm (primary inspiratory muscle) to flatten the latter and the external intercostal muscles to raise the ribs. This brings about inspiration.

(ii) **Ventral Respiratory Group.** It is located in the ventrolateral part of the medulla oblongata and mainly causes inspiration. It issues signals for both **inspiration** (to diaphragm and external intercostal muscles) and **expiration** (to internal intercostal muscles and muscles of abdominal wall).

(iii) **Pneumotaxic centre.** It is located in the dorsal part of pons varolii. It issues impulses to all the neurons of the dorsal respiratory group and only to the inspiratory neurons of ventral respiratory group. These impulses regulate the time of inspiration in both normal and abnormal breathing. The primary effect of these is to control the 'switch off' point of inspiratory signal. Therefore, the *function* of the pneumatic centre is primarily *to limit inspiration.*

There is another strange centre called the **apneustic centre**, located in the lower part of the pons varolii. It is thought that it operates in association with the pneumotoxic centre to control the depth of inspiration.

2. **Chemical Regulation of Respiration.** The largest number of **chemoreceptors** are located in the **carotid bodies**. However a sizeable number of chemoreceptors are in the **aortic bodies.**

These chemoreceptors of carotid and aortic bodies are stimulated by an increase in carbon dioxide concentration and by an increase in hydrogen ion concentration (*p*H) in the arterial blood. Increased CO_2 lowers the *p*H resulting **acidosis**. These chemoreceptors send signals to the inspiratory and expiratory centres. Thus rate of breathing is increased.

However oxygen does not seem to have a significant effect on the respiratory centre.

Disorders of Respiratory System

Bronchitis. It is the inflammation of the bronchi and caused by an infection. It may also be caused by cigarette smoking and exposure to air pollutants like carbon monoxide. The linings of the bronchi swell and produce excess mucus. The typical symptom is regular coughing with thick greenish yellow sputum that indicates the underlying infection.

Asthma. It is usually due to an allergic reaction to foreign substances that affects the respiratory tract. Allergens (which cause allergy) stimulate the release of histamine from the mast cells. Histamine has several effects, one of which is to cause bronchiolar smooth muscle to contract. The symptoms of bronchial asthma may be coughing, wheezing (breathing noisily), difficulty in breathing mainly during expiration. These symptoms are often worst at night.

Emphysema. Many of the septa between the alveoli are destroyed and much of the elastic tissue of the lungs is replaced by connective tissue. Major causes are cigarette smoking and the inhalation of other smoke or toxic substances over a period of time. As the alveolar septa collapse, the surface area for gas exchange is greatly reduced. As a result, the alveolar sacs remain filled with air even after expiration. The exhalation becomes more difficult. The lungs remain inflated. One must avoid air pollutants. There is no permanent cure for the disease.

Diseases such as bronchitis, bronchial asthma and emphysema have in common some degree of obstruction of the air passage ways. The term **chronic obstructive pulmonary disease (COPD)** is used to refer to these disorders.

Pneumonia. It is an acute infection or inflammation of the alveoli of the lung. Pneumonia is caused mainly by bacteria *Streptococcus pneumoniae*. Some times, other bacteria or fungi, protozoans viruses and mycoplasma may cause pneumonia. The alveoli become acutely inflamed. Most of

SARS. It is a type of pneumonia called severe acute respiratory syndrome. It is caused by variant of common cold *corona* virus which spreads by droplet and other method. There is an initial fever (100.4°F), headache, body aches, dry cough and the difficult breathing.

Coughing. Preceded by a long-drawn and deep inspiration that is followed by a complete closure of the glottis-resulting strong expiration suddenly pushes glottis open and sends a blast of air through the upper respiratory passages. Stimulus for the reflex act could be a foreign body lodged in the larynx, trachea, or epiglottis.

Sneezing. Spasmodic contraction of muscles of expiration forcefully expels air through the nose and mouth. Stimulus may be an irritation of the nasal mucosa.

Yawning. A deep inspiration through widely opened mouth producing an exaggerated depression of the lower jaw. May be stimulated by drowsiness or fatigue, but precise stimulus-receptor cause is unknown.

Hiccough. Spasmodic contraction of the diaphragm followed by a spasmodic closure of the glottis produces a sharp inspiratory sound. Stimulus is usually irritation of the sensory nerve endings of digestive tract.

Apnea – no breathing or almost nil.

Rhinitis. Chronic or acute inflammation of the mucus membrane of the nose.

Dyspnea. Painful breathing.

Orthopnea. Inability to breathe in a horizontal position.

Cyanosis. Bluish colouration of skin and mucous membrane due to reduced haemoglobin in blood.

Pleurisy. An inflammation of pleural membranes.

Whooping Cough (Pertussis). Cough with inspiratory whoop caused by *Bordetella pertussis*.

READ AND DIGEST

- In an organism the minimum rate of energy conversion required just to stay alive during complete rest or sleep is called **basal metabolic rate** (BMR).
- **Eupnea.** True breathing– normal breathing.
- **Hyperpnea.** Breathing rate high— above normal.
- **Hypopnea.** Breathing rate low— below normal.
- Olfactory epithelium is also called **Schneiderian membrane**.
- **In some turtles,** cloaca acts as respiratory organ.
- **Philip Drinker,** an American Engineer invented **iron lung (= Drinker's Respirator** or **Tank Respirator)** in 1929.
- **Turbinals** (nasal conchae) are derived from nasals, maxillae and ethmoids.
- Diaphragm is supplied with blood by **phrenic artery**.
- **CRD**— Chronic respiratory diseases.
- A swim bladder is not found in the **flat fishes**.
- **Slug** (a mollusc) is purely an air-breather.
- *Oniscus* – 'Wood louse' (a crustacean) is an air-breather.

Respirtory Pigments.

- **Haemoglobin.** It is red coloured pigment. It is formed of iron and protein.
- **Haemocyanin.** It is blue coloured pigment. It is formed of copper and protein. It occurs in the blood plasma of Arthropods (e.g., *Limulus, Daphnia* and prawn) and Molluscs (e.g., *Pila, Sepia, Octopus,* and *Helix*)

- **Chlorocruorin.** It is green coloured pigment. It was discovered by **Milne Edwards** in Annelids. It is an iron containing blood pigment. It occurs in the blood plasma of polychaete Annelids (*e.g., Sabella, Serpula*)
- **Haemoerythrin.** It is reddish-violet coloured pigment. It is formed of iron and protein. It occurs in *Sipunculus* (commonly known as "pea-nut worm"), and the polychaete Magelona. Haemoerythrin is less efficient in oxygen carrying capacity.
- **Pinnaglobin.** It is brown coloured pigment. It is manganese containing blood pigment. It occurs in the blood fluid of some molluscs (*e.g., Pinna*).
- **Echinochrome.** It is red coloured pigment. It is an iron containing pigment. It occurs in the coelomic fluid of sea urchin (echinoderm).
- **Vanadium.** It is present in the blood of many tunicates (urochordates). Most tunicates can extract the rare metal Vanadium from sea water. *Ciona* contains vanadium in the plasma and *Ascidia* in special green blood corpuscles called *vanadocytes*. *Herdmania* can not extract vanadium from sea water. Its oxygen absorbing power is very low and real function is uncertain.
- **Molpadin.** It occurs in *Molpadia* (phylum Echinodermata. class Holothuroidea, order Molpadonia).

MULTIPLE CHOICE QUESTIONS

1. If the thoracic wall but not lungs is punctured
   (1) the lungs get inflated
   (2) the man dies as the lungs get collapsed
   (3) the breathing rate decreases
   (4) the breathing rate increases
2. Inflammation of the lung covering causing severe chest pain is
   (1) Emphysema (2) Pleurisy
   (3) Asphyxia (4) Hypoxia
3. In human beings the number of lobes in right and left lungs is
   (1) 2 and 3 (2) 2 and 2
   (3) 3 and 2 (4) 4 and 2
4. What would happen when blood is acidic?
   (1) Binding of Oxygen with haemoglobin increases
   (2) Red blood corpuscles are formed in higher number
   (3) Binding of oxygen with haemoglobin decreases
   (4) There is no change in oxygen binding nor number of RBC.
5. Residual air mostly occurs in
   (1) alveoli (2) bronchus
   (3) nostrils (4) trachea
6. Common factors in the trachea of mammals and insects is
   (1) ciliated inner lining
   (2) noncollapsible wall
   (3) paired nature
   (4) origin from head region
7. What is usually present at the time of asphyxiation?
   (1) Oxyhaemoglobin
   (2) Methaemoglobin
   (3) Carbaminohaemoglobin
   (4) Carboxyhaemoglobin
8. Trachea is lined with incomplete rings of
   (1) fibrous cartilage
   (2) calcified cartilage
   (3) elastic cartilage
   (4) hyaline cartilage
9. Amount of oxygen present in one gram of haemoglobin is
   (1) 20 ml (2) 1.34 ml
   (3) 13.4 ml (4) None of the above
10. Total oxygen that can be carried by blood in one minute is about
   (1) 1000 – 1200 ml (2) 2000 – 3000 m
   (3) 200 ml (4) 100 ml
11. Oxygen carried by blood is liberated in
   (1) arteries
   (2) capillaries of body
   (3) capillaries of lungs
   (4) heart
12. Respiratory centre of brain is mainly stimulated by
   (1) Carbon dioxide content in venous blood
   (2) Carbon dioxide content in arterial blood
   (3) Oxygen content in venous blood
   (4) Oxygen content in arterial blood
13. Gases diffuse over the respiratory surface because of PO_2
   (1) is more in alveoli than in blood
   (2) is more in blood than in tissues
   (3) is less in alveoli than in blood
   (4) is less in blood than in tissues
14. Dead space is
   (1) respiratory tract
   (2) nasal chambers only
   (3) alveolar space
   (4) pleural cavity
15. In lungs there is definite exchange of ions between RBC and plasma. Removal of CO_2 from blood involves
   (1) Influx of Cl' into RBC
   (2) Efflux of Cl' from plasma
   (3) Influx of HCO_3' ions in RBC
   (4) Efflux of HCO_3 ions from RBC
16. Which statements are true/false?
   (i) Blood transports CO_2 comparatively easily because of its high solubility
   (ii) Approximately 8.9% of CO_2 is transported dissolved in plasma
   (iii) CO_2 diffuses into blood, passes into RBCs and reacts with water to form H_2CO_3
   (iv) Oxyhaemoglobin of erythrocytes is basic

(v) Chloride ions diffuse from plasma into erythrocytes to maintain ionic balance

(1) (i), (iii) and (v) are true, (ii) and (iv) are false
(2) (i), (iii) and (v) are false, (ii) and (iv) are true
(3) (i), (ii) and (iv) are true, (iii) and (v) are false
(4) (i), (ii) and (iv) are false, (iii) and (v) are true

17. Which is true?
(1) P_{CO_2} of deoxygenated blood is 95 mm Hg
(2) P_{CO_2} of alveolar air is 40 mm Hg
(3) P_{CO_2} of oxygenated blood is 95 mm Hg
(4) P_{CO_2} of deoxygenated blood is 40 mm Hg

18. With decrease in temperature oxyhaemoglobin curve will become
(1) straight (2) more steep
(3) parabola (4) none of these

19. Which is true?
(1) H^+ ions released from carbonic acid combine with haemoglobin to form haemoglobinic acid
(2) Oxyhaemoglobin of erythrocytes is alkaline
(3) More than 70% of carbon dioxide is transferred from tissue to lungs as carbamino compounds
(4) In healthy person, haemoglobin content is more than 25g/100 ml.

20. Which is the correct sequence of the air passage in man?
(1) Nasal cavity → pharynx → trachea → larynx → bronchi → bronchioles → alveoli
(2) Nasal cavity → pharynx → larynx → trachea → bronchi → bronchioles → alveoli
(3) Nasal cavity → larynx → pharynx → trachea → bronchi → bronchioles → alveoli
(4) Nasal cavity → larynx → bronchi → pharynx → trachea → bronchioles → alveoli

21. Food and air pathways are divided at
(1) larynx (2) pharynx
(3) stomach (4) oesophagus

22. Glottis is an opening in the floor of
(1) mouth (2) trachea
(3) pharynx (4) diaphragm

23. Thyroid cartilage and arytenoid cartilage are found in
(1) thyroid gland (2) pharynx
(3) larynx (4) ear pinna

24. Adam's apple represents
(1) cricoid cartilage (2) thyroid cartilage
(3) pharynx (4) none of these

25. The structure which does not contribute to the breathing movements in mammals is
(1) rib (2) larynx
(3) diaphragm (4) intercostal muscles

26. In human beings, oblique fissures are found in
(1) right lung (2) left lung
(3) both lungs (4) diaphragm

27. Even when there is no air in it, trachea does not collapse due to the presence of
(1) bony rings (2) turgid pressure
(3) chitinous rings
(4) cartilaginous rings

28. Lining of trachea is made up of
(1) stratified ciliated epithelium
(2) pseudostratified ciliated epithelium
(3) simple squamous epithelium
(4) stratified cuboidal epithelium

29. The narrowest and most numerous tubes of lungs are termed as
(1) hilum (2) alveoli
(3) tracheae (4) bronchioles

30. Terminal bronchioles branch to form
(1) alveoli (2) bronchioles
(3) alveolar duct
(4) respiratory bronchiole

31. Which one of the following has the smallest diameter?
(1) Trachea
(2) Secondary bronchiole
(3) Respiratory bronchiole
(4) Left primary bronchus

32. Lung alveoli of mammals have a thin wall composed of
(1) simple cuboidal epithelium
(2) simple squamous epithelium
(3) stratified cuboidal epithelium
(4) stratified squamous epithelium

33. The alveolar epithelium in the lung is
(1) ciliated columnar
(2) ciliated squamous
(3) nonciliated squamous
(4) nonciliated columnar

34. Presence of large number of alveoli around alveolar ducts opening into bronchioles in mammalian lungs is
(1) an efficient system of ventilation with no residual air
(2) an efficient system of ventilation with little residual air
(3) inefficient system of ventilation with little of residual air
(4) inefficient system of ventilation with high percentage of residual air

35. Which structures are responsible for breathing process?
(1) Larynx and bronchi
(2) Tracheae and alveoli
(3) Ribs and intercostal muscles
(4) Intercostal muscles and diaphragm

36. Which of the following statements is correct?
(1) Inspiration is an active process
(2) Inspiration is a passive process
(3) Expiration is an active process
(4) Both expiration and inspiration are passive processes

37. During expiration the diaphragm becomes
(1) normal (2) oblique
(3) flattened (4) dome-shaped

38. During inspiration, the diaphragm
(1) relaxes to become dome-shaped
(2) contracts and flattens
(3) shows no change
(4) expands

39. Which one of the following is called inspiratory muscle in mammals?
(1) Pleural muscle
(2) External intercostal muscle
(3) Internal intercostal muscle
(4) Abdominal muscles

40. During inspiration in mammals, the sternum moves
(1) forward and upward
(2) backward and upward
(3) forward and downward
(4) backward and downward

41. Which is correct?
(1) A human lung has 1000 alveoli
(2) Respiratory centres are not affected by CO_2
(3) During inspiration the lungs act as suction pump
(4) In human vital capacity is just double the expiratory volume

42. The contraction of internal intercostal muscles in man causes
(1) normal expiration
(2) inspiration
(3) forced expiration
(4) normal respiration

43. During forced expiration, actively contracting muscles include the
(1) diaphragm
(2) external intercostals
(3) abdominal muscles
(4) all of these

44. With reference to human respiration, which is correct ?
(1) Pulmonary ventilation is equal to alveolar ventilation
(2) Alveolar ventilation is more than pulmonary ventilation
(3) Pulmonary ventilation is less than alveolar ventilation
(4) Alveolar ventilation is less than pulmonary ventilation

45. Rate of breathing in an adult human is
(1) 10-12/min (2) 12-18/min
(3) 20-25/min (4) 30-35/min

46. The breathing rate in a child is
(1) more than in an adult man
(2) less than in an adult man
(3) same as in an adult man
(4) none of the above

47. Which of the following statements best summarises the relationship between respiratory rate and body size in related animals?
(1) Larger the animal higher the respiratory rate
(2) Smaller the animal lower the respiratory rate
(3) Smaller the animal higher the respiratory rate
(4) Size and respiratory rate are not related in any fashion

48. Which of the following conditions can cause an increase in ventilation rate of lungs?
(1) Increase in O_2 content of inhaled air
(2) Decrease in O_2 content of exhaled air
(3) Increase of CO_2 content in inhaled air
(4) Increase of CO_2 content in exhaled air

49. Exchange of gases between blood and alveolar air in lungs occurs by
(1) active transport (2) simple diffusion
(3) osmosis (4) all of these

50. The volume of air breathed in and out during a normal breathing by man is called
(1) tidal volume (2) vital capacity
(3) residual volume
(4) inspiratory reserve volume

51. Tidal volume in human beings is
(1) 500 mL (2) 800 mL
(3) 1000 mL (4) 1200 mL

52. About 1200 mL of air is always known to remain inside the human lungs. It is described as
(1) functional residual capacity
(2) residual volume
(3) expiratory reserve volume
(4) inspiratory reserve volume

53. The amount of air remaining in the air passages and alveoli at the end of quiet respiration is
(1) tidal volume
(2) residual volume
(3) inspirating reserve volume
(4) functional residual capacity

54. After deep inspiration, maximum expiration of lungs is called
(1) Vital capacity
(2) Total lung capacity
(3) Inspiratory capacity
(4) Functional residual capacity

55. Vital capacity of lungs is
(1) IRV + ERV
(2) IRV + ERV + TV
(3) IRV + ERV + TV – RV
(4) IRV + ERV + TV + RV

56. The vital capacity of adult human being is about
(1) 1200 mL (2) 2400 mL
(3) 4000 mL (4) 6000 mL

57. After the expiration of a normal tidal volume, a person breathes in as much as air possible. The volume of air inspired is the
(1) vital capacity
(2) inspiratory capacity
(3) inspiratory reserve volume
(4) total lung capacity

58. The maximum amount of air that our lung can normally hold is
(1) vital capacity (2) tidal capacity
(3) total lung capacity
(4) pulmonary capacity

59. The total lung capacity is represented by
(1) tidal volume + vital capacity
(2) tidal volume + functional residual capacity
(3) vital capacity + residual volume
(4) inspiratory and expiratory reserve volumes

60. Arrange the following in the order of increasing volume
1. Tidal volume
2. Residual volume
3. Inspiratory reserve volume
4. Vital capacity
(1) $1 < 3 < 2 < 4$ (2) $1 < 2 < 3 < 4$
(3) $1 < 4 < 3 < 2$ (4) $1 < 4 < 2 < 3$

61. Match the items in Column I with Column II and choose the correct option

Column I	Column II
A Tidal volume	1. 2500 to 3000 mL of air
B Inspiratory reserve volume	2 1000 mL of air
C Expiratory reserve volume	3. 500 mL of air
D Residual volume	4. 3400 to 4800 mL of air
E Vital capacity	5 1200 mL of air

(1) A = 3, B = 4, C = 2, D = 1, E = 5
(2) A = 3, B = 1, C = 4, D = 5, E = 2
(3) A = 5, B = 4, C = 2, D = 1, E = 2
(4) A = 3, B = 1, C = 2, D = 5, E = 4

62. Given these lung volumes.
1. Tidal volume = 500 mL
2. Residual volume = 1000 mL
3. Inspiratory reserve volume = 2500 mL

4. Expiratory reserve volume = 1000 mL
5. Dead space = 1000 mL

The functional residual capacity (FRC) is
(1) 3500 mL (2) 2000 mL
(3) 6000 mL (4) 3000 mL

63. The alveolar ventilation is the
(1) amount of air available for gas exchange in the lungs
(2) vital capacity divided by the respiratory rate
(3) tidal volume times the respiratory rate
(4) minute ventilation plus the dead space

64. Partial pressure of oxygen in lungs is
(1) 104 mmHg (2) 120 mmHg
(3) 40 mmHg (4) 90 mmHg

*65. Which is true for CO_2 partial pressure?
(1) More in inspired air than in expired air
(2) More in alveolar air than in expired air
(3) More in expired air than in alveolar air
(4) More in inspired air than in alveolar air

66. How the transport of O_2 and CO_2 by blood happens?
(1) With the help of RBCs and WBCs
(2) With the help of WBCs and blood serum
(3) With the help of platelets and plasma
(4) With the help of RBCs and blood plasma

67. Oxygen is transported in blood mainly by
(1) leucocytes (2) erythrocytes
(3) serum (4) blood plasma

68. Which form of iron is found in haemoglobin?
(1) Fe^{2+} (2) Fe^{3+}
(3) In the form of molecule
(4) In the form of FeO

69. The chemical formula of oxyhaemoglobin is
(1) $Hb(O_2)_4$ (2) $Hb(O_3)_4$
(3) Hb_2O_4 (4) $Hb(O_2)_6$

70. How many molecules of oxygen can associate with a molecule of haemoglobin in man?
(1) One (2) Two
(3) Three (4) Four

71. The most important physiological feature of haemoglobin is
(1) Its red colour
(2) Presence of iron
(3) Presence of basic protein globin
(4) Its ability to combine reversibly with oxygen

72. The total percentage of oxygen transported by the haemoglobin is
(1) 3% (2) 70% (3) 97% (4) 100%

73. The percentage of haemoglobin saturated with oxygen will increase if the
(1) arterial pH is decreased
(2) temperature is increased
(3) arterial P_{O_2} is increased
(4) CO_2 concentration is increased

74. Which of the following increases the oxygen-affinity of Hb?
(1) High body temperature
(2) Low P_{CO_2}
(3) Low blood pH (4) Both (2) and (3)

75. In which condition, oxygen dissociation curve of haemoglobin shift to right of normal curve?
(1) Decrease in pH
(2) Decrease in acidity
(3) Decrease in temperature
(4) Decrease in CO_2 concentration

76. Dissociation of oxyhaemoglobin can be promoted by
(1) low (2) high P_{CO_2}
(3) high blood pH
(4) low body temperature

77. What would happen if human blood becomes acidic (low pH)?
(1) WBC count increases
(2) RBC count decreases
(3) Oxygen carrying capacity of haemoglobin increases
(4) Oxygen carrying capacity of haemoglobin decreases

78. When partial pressure of CO_2 (P_{CO_2}) rises, the oxygen dissociation curve of haemoglobin will
(1) shift towards left
(2) become irregular
(3) remain unchanged
(4) shift towards right

79. An increase in the P_{50} of an oxyhaemoglobin curve would result from a decrease in
(1) pH (2) carbondioxide
(3) metabolism (4) temperature

*65. The partial pressure of CO_2 in alveolar air is 40 mmHg while in expired air, it is 32 mmHg.

80. Bohr effect is the effect of
(1) CO_2 on RBCs
(2) O_2 on haemoglobin
(3) CO_2 on haemoglobin
(4) CO_2 on oxyhaemoglobin

81. Which statement correctly defines Bohr effect?
(1) Fall in P_{50} with a decrease in *p*H
(2) Rise in P_{50} with a decrease in CO_2 concentration
(3) Rise in P_{50} with an increase in CO_2 concentration
(4) Rise in P_{50} with an increase in pH and decrease in P_{CO_2}

82. Which of the following factors raise the P_{50} value and shifts the HbO_2 dissociation curve to right?
1. Rise in P_{CO_2}
2. Fall in temperature
3. Rise in H^+ ions
4. Fall in diphosphoglyceric acid

Answer codes :
(1) 1 and 2 are correct
(2) 2 and 4 are correct
(3) 1 and 3 are correct
(4) 1,2 and 3 are correct

83. In which form CO_2 is carried in blood?
(1) Sodium bicarbonate
(2) Sodium carbonate
(3) Potassium carbonate
(4) Magnesium carbonate

84. Bicarbonate ions are generated in
(1) RBCs (2) Basophil
(3) Neutrophil (4) Lymphocytes

85. In mammals, carbon dioxide is transported from tissues to respiratory surface by
(1) Plasma only
(2) RBCs and WBCs
(3) Plasma and RBCs
(4) Red blood corpuscles only

86. Enzyme involved in CO_2 transport in blood is
(1) carboxylase (2) carboxykinase
(3) carbonic anhydrase (4) none of these

87. Statements
(A) Carbonic anhydrase is present in the erythrocytes
(B) In erythrocytes the carbon dioxide combine with water and is transported
(1) Statement (A) is correct and is responsible for statement (B)
(2) Statement (A) is not correct but statement (B) is correct
(3) Both statements (A) and (B) are wrong
(4) Statement (A) is correct but not involved in statement (B)

88. In lungs, there is definite exchange of ions between RBC and plasma. Removal of CO_2 from blood involves
(1) influx of Cl^- ions into RBC
(2) efflux of Cl^- ions from RBC
(3) influx of Na^+ ions into RBC
(4) efflux of ions from RBC

89. Hamburger's phenomenon explains
(1) chloride shift
(2) formation of HCO_3
(3) breathing mechanism
(4) oxygen saturation of Hb

90. Chloride shift occurs in response to
(1) H^+ (2) K^+
(3) Na^+ (4) HCO_3^-

91. In the process of transport of CO_2 which phenomenon occurs between RBCs and plasma?
(1) Osmosis (2) Adsorption
(3) Absorption (4) Chloride shift

92. Which of the following statements are true/false?
A. The blood transports CO_2 comparatively easily because of its higher solubility.
B. Approximately 10% of CO_2 is transported being dissolved in the plasma of blood.
C. The carbon dioxide produced by the tissues, diffuses passively into the blood stream and passes into red blood corpuscles and react with water to form H_2CO_3.
D. The sodium ions diffuse from plasma into the erythrocytes to maintain ionic balance.
E. The chloride ions diffuse from plasma into the erythrocytes to maintain ionic balance.
(1) A, C and E are true, B and D are false
(2) A, B and D are false, C and E are true
(3) A, B and C are true, D and E are false
(4) A, B and D are true, C and E are false

93. As the P_{CO_2} of the venous blood increases the
(1) blood pH decreases
(2) concentration of HCO_3^- decreases
(3) amount of chloride in the RBCs decreases
(4) affinity of the haemoglobin for O_2 increases

94. Which of these statements about the partial pressure of CO_2 is true?
(1) It is higher in the alveoli than in pulmonary arteries
(2) It is higher in the systemic arteries than in the tissues
(3) It is higher in the systemic veins than in the systemic arteries
(4) It is higher in the pulmonary veins than in pulmonary arteries

95. Haemoglobin is having maximum affinity with
(1) NH_3 (2) O_2 (3) CO (4) CO_2

96. When man inhales air containing normal concentration of O_2, but also carbon monoxide, he suffers from suffocation because
(1) Haemoglobin combines with CO instead of with O_2 and product cannot dissociate
(2) CO reacts with O_2 reducing percentage of O_2 in the blood
(3) CO affects the diaphragm and intercostal muscles
(4) CO affects the nerve of the lungs

97. Carbon monoxide has greater affinity for haemoglobin as compared to oxygen
(1) 2 times (2) 20 times
(3) 250 times (4) 1000 times

98. Pneumotaxic centre which can moderate the functions of the respiratory rhythm centre is present at
(1) thalamus (2) spinal cord
(3) pons varolii
(4) left cerebral hemisphere *(Kerala PMT 2011)*

99. The inspiratory and expiratory centres in man are located in
(1) pons (2) cerebellum
(3) medulla oblongata
(4) one in pons and the other in cerebellum

100. The Dorsal Respiratory Group (DRG) is located in
(1) dorsal portion of pons
(2) ventral portion of pons
(3) dorsal portion of medulla oblongata
(4) ventral portion of medulla oblongata

101. Which of these parts of the brainstem is correctly matched with its main function?
(1) Ventral respiratory groups-stimulate the diaphragm contraction
(2) Dorsal respiratory groups-limit inflation of the lungs
(3) Pontine respiratory group-switch between inspiration and expiration
(4) All of the above

102. The respiratory centre in medulla may release motor impulses for faster breathing due to
(1) venous blood leaving it
(2) arterial blood leaving it
(3) venous blood entering into it
(4) arterial blood entering into it

103. Respiratory centre of brain is sensitive to
(1) more CO_2 concentration in blood
(2) more O_2 concentration in blood
(3) accumulation of blood in brain
(4) all of the above

104. Rate of breathing is maximally affected by
(1) oxygen in trachea
(2) concentration of O_2
(3) concentration of CO_2
(4) diaphragm expansion

105. Impulse for voluntary force breathing starts in
(1) medulla (2) cerebrum
(3) spinal cord (4) vagus nerve

106. The number of RBCs in man increases if he lives at a higher altitude because
(1) there is less oxygen in mountains
(2) there is more oxygen at the mountains
(3) there are no germs in the air in mountain
(4) more heat is required to be produced in the body for keeping warm

107. If a person, living at sea level, migrates to about 8000 feet high hill, his blood after about fifteen days will mainly
(1) have fewer WBCs
(2) have more plasma
(3) have increase in volume of serum
(4) have greater number of RBCs and more haemoglobin

108. When some food particle enters the wind-

pipe instead of oesophagus, it is expelled by the process of
(1) sneezing (2) coughing
(3) yawning (4) hiccupping

109. Lack of breathing is
(1) apnea (2) eupnea
(3) dyspnea (4) asphyxia

110. Ordinary quiet breathing is
(1) apnea (2) Eupnea
(3) dyspnea (4) asphyxia

111. Asthma is caused due to
(1) infection of lungs
(2) infection of trachea
(3) spasm in bronchial muscles
(4) bleeding into pleural cavity

112. In which disease, due to narrowing of tracheal passages, alveoli are deprived of oxygen?
(1) Asthma (2) Bronchitis
(3) Pneumonia (4) Emphysema

113. Which of the following is not true about asthma?
(1) The basic defect is chronic airway inflammation
(2) The airway smooth muscle is hyperresponsive
(3) It can be treated with bronchiodilator therapy
(4) It is always caused by an infection

114. In heavy smokers the alveoli of the lungs are enlarged and damaged which reduces the surface area of the exchange of respiratory gases. This condition is called
(1) asthma (2) silicosis
(3) insomnia (4) emphysema

115. Match the disorders given in column I with symptoms under column II. Choose the answer which gives the correct combination of alphabets with numbers.

Column I	Column II
A Asthma	1. Inflammation of nasal tract
B Bronchitis	2. Spasm of tracheal muscle
C Rhinitis	3. Fully blown out alveoli
D Emphysema	4. Inflammation of bronchi
	5. Cough with blood stained sputum

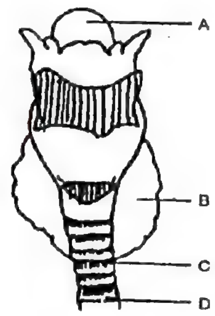
Answer codes :
(1) A = 4, B = 2, C = 5, D = 1
(2) A = 2, B = 4, C = 1, D = 3
(3) A = 5, B = 3, C = 2, D = 1
(4) A = 3, B = 1, C = 5, D = 4

116. Hypoxia is the condition in which less oxygen becomes available to the tissues. This may be due to
(1) lesser oxygen in the atmosphere
(2) blockage in air passage
(3) less RBCs in blood
(4) all of the above

117. Whether a child died after normal birth or died before birth can be confirmed by measuring
(1) the dead space air
(2) tidal volume of air
(3) residual volume of air
(4) the weight of the child

118. About 97% of O_2 is transported by RBCs. The remaining 3% is
(1) present in peroxisomes
(2) remains in lungs
(3) trapped inside the mitochondria
(4) dissolved in plasma and transported

119. The diagram represents the human larynx. Choose the correct combination of labelling from the options given



(1) A = Larynx, B = Parathyroid, C = Tracheal cartilage, D = Trachea
(2) A = Nasolarynx, B = Thyroid, C = Tracheal cartilage, D = Trachea
(3) A = Trachea, B = Thyroid, C = Bronchiole, D = Tracheal cartilage
(4) A = Epiglottis, B = Thyroid, C = Tracheal cartilage, D = Trachea

120. Lack of pulmonary surfactant produces
(1) asthma (2) emphysema
(3) cystic fibrosis
(4) respiratory distress syndrome

121. In the resting person, saturation of haemoglobin as blood leaves the tissue capillaries is approximately
(1) 75% (2) 40% (3) 3% (4) 46%

122. Read the following statements and select the correct one
(1) Oxyhaemoglobin of erythrocytes is alkaline
(2) In a healthy person, the haemoglobin content is more than 25 g per 100 mL
(3) In lungs, the oxygen from the alveolus reaches the blood through active transport
(4) The H^+ released from carbonic acid combines with haemoglobin to form haemoglobinic acid

123. When the oxygen supply to the tissue is inadequate, the condition is
(1) Asphyxia (2) Apnea
(3) Dyspnea (4) Hypoxia

124. Oxygen affinity of haemoglobin is increased by all of the following except
(1) Alkalosis (2) Hypoxia
(3) Increased HbF (4) Hypothermia

125. All are features of exercise except
(1) left shift of Hb – O_2 dissociation curve
(2) increased blood supply to muscle
(3) increase stroke volume
(4) increase O_2 extraction

126. Vital capacity, the maximum volume of air a person can exhale after maximum inhalation is measured with
(1) Spirometer (2) Stethoscope
(3) Aspirator
(4) Sphygmomanometer

*127. Go through the following statements carefully
(i) The diaphragm and internal intercostal muscles are the inspiratory muscles.
(ii) The diffusion of carbon dioxide is 20 times faster than oxygen and that of oxygen is two times faster than nitrogen.
(iii) The exchange in gases between alveoli and blood capillaries is called external respiration and between blood capillaries and tissue cells is called internal respiration.
(iv) Cyanosis is caused by excessive amount of deoxygenated haemoglobin in the blood vessels.

Which of these are correct?
(1) (i), (ii)& (iii) (2) (ii), (iii) & (iv)
(3) (i), (iii) & (iv) (4) (iii) & (iv)

*128. Go through the following statements
(i) The oxygen-haemoglobin dissociation curve is a sigmoid curve.
(ii) About 4.5 ml of CO_2 can combine with Hb in 100 ml of blood in the form of carbamino-haemoglobin
(iii) High PO_2 tends to displace CO_2 from haemoglobin and this is called Haldane effect.
(iv) The movement of chloride ions from plasma into RBCs at the time of CO_2 transport is called Hamburger's phenomenon.

Which of these are correct?
(1) (i), (ii) & (iii) (2) (i), (iii) & (iv)
(3) (ii), (iii) & (iv) (4) All are correct

129. Which match is incorrect?

	Respiratory capacity	Defined as	Amount (ml) (approx.)
(1)	Inspiratory capacity	T.V. + IRV	3500
(2)	Vital Capacity	ERV+IRV+RV	5000
(3)	Functional residual capacity	ERV + RV	2200
(4)	Expiratory capacity	TV + ERV	1500

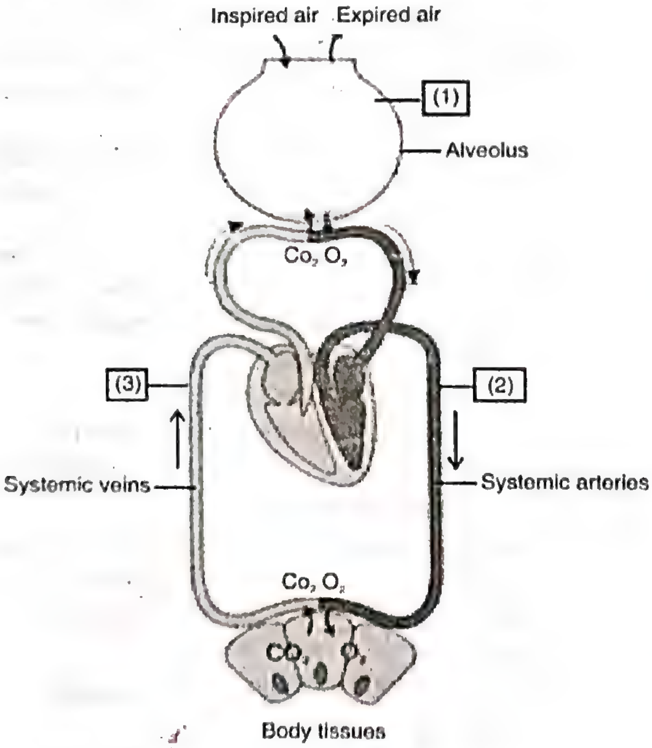
130. Read the following statements about Human Respiration
(i) Trachea divides at the level of 6th Thoracic vertebra
(ii) Terminal bronchioles, alveoli and their ducts form the respiratory part of this system
(iii) Contraction of diaphragm increases volume of thoracic chamber dorsoventrally
(iv) The internal intercostals help in inspiration

Choose the best option
(1) All except (iv) are true

*127. Diaphragm and external intercostal are the inspiratory muscles.
*128. About 1.5 ml of CO_2 can combine with Hb in 100 ml of blood in the form of carbaminohaemoglobin.

(2) Only (iii) and (iv) are false
(3) Only (i) is true
(4) None is true

131. The following diagram shows exchange of gases between alveolus and body tissues with direction of flow of blood indicated.



Which option correctly indicates the normal pCO_2 levels (in mm Hg) in 1, 2, and 3 in order?
(1) 104, 95, 45 (2) 40, 40, 45
(3) 40, 45, 45 (4) 40, 40, 95

132. When CO_2 is exhaled out of the lungs, which layers does it pass through in the correct order from inside to outside?
(1) Ciliated epithelium, basement membrane, Endothelium
(2) Endothelium, Basement membrane; simple cuboidal epithelium
(3) Simple squamous epithelium, Basement membrane, Endothelium
(4) Endothelium, Basement membrane; Simple squamous epithelium

133. Four possibilities for the transport of carbon dioxide from the body cells to the lungs are listed below. Which possibility does not exist?
(1) Bound to the ferro-ions of haemoglobin in erythrocytes
(2) As a hydrocarbonate ion in the buffering system of the blood
(3) Bound to the protein of haemoglobin in erythrocytes
(4) Dissolved in blood plasma and in erythrocyte cytoplasm

134. A yoga teacher is demonstrating the technique of breathing exercises. During forced expiration, the actively contracting muscles in his body include -
(1) diaphragm
(2) sternocleidomastoid
(3) abdominal muscles
(4) external intercostals

135. Arrange the following in an ascending order of volume.
1. Expiratory reserve volume
2. Inspiratory capacity
3. Tidal volume
4. Residual volume
(1) (iii) < (i) < (iv) < (ii)
(2) (iv) < (i) < (iii) < (ii)
(3) (iv) < (ii)< (i) < (iii)
(4) (iii) < (iv) < (ii) < (i)

136. Increase in concentration of bicarbonates in blood plasma would result in increased
(1) ventilation of lungs (2) urination
(3) ultrafiltration (4) salivation

137. The correct statements about respiration are
(i) In cockroach gaseous exchange occurs mainly between tracheoles and haemolymph
(ii) Increase in inspiratory capacity does not involve an increase in tidal volume
(iii) Partial pressure of oxygen in blood is less than that in alveoli
(iv) Chloride shift in erythrocytes maintain the ionic balance
(1) (i) and (ii) (2) (i), (iii) and (iv)
(3) (i), (ii) and (iv) (4) (ii) and (iii)

138. Read the following statements
(i) The point of bifurcation of trachea is called carina and is at the level of 5th thoracic vertebra.
(ii) The right bronchus is shorter, wider and more in line with trachea than the left bronchus.
(iii) The bronchioles are without cartilaginous rings.

(iv) The surfactant of lungs is secreted in infants between 6th and 7th month of life.

Which of these are correct?

(1) (i), (ii) & (iii)
(2) (ii), (iii) & (iv)
(3) (i), (iii) & (iv)
(4) All are correct

*139. Go through the following matches

(i) Functional residual capacity = ERV + IRV + RV
(ii) Expiratory capacity = TV + ERV
(iii) Vital capacity = ERV + TV + IRV
(iv) Total lung capacity = RV + ERV + IRV

Which of these are correct?

(1) (i), (ii) & (iii)
(2) (ii), (iii) & (iv)
(3) (i) & (iii)
(4) (ii) & (iii)

*140. Go through the following values

(i) Residual volume – 1200 ml
(ii) Vital capacity – 5.5 to 6.5 litres
(iii) Expiratory reserve volume – 1100 ml
(iv) Minute respiratory volume – 6000 to 8000

Which of these are correct?

(1) (i), (ii) & (iii)
(2) (ii), (iii) & (iv)
(3) (i), (iii) & (iv)
(4) All are correct

*141. Go through the following statements

(i) The peripheral chemoreceptors for regulation of respiration are located in carotid veins and arch of aorta.
(ii) The primary effect of pneumotaxic centre is to control the switch-off point of inspiratory signal and thus limit inspiration.
(iii) The chemosensitive area of brain for respiratory control is highly sensitive to O_2 concentration.
(iv) In case of foetal haemoglobin, the oxygen haemoglobin dissociation curve is shifted toward left.

Which of these are correct?

(1) (i), (iii) &(iv)
(2) (ii) and (iv)
(3) (ii), (iii) & (iv)
(4) (iii) and (iv)

*142. Go through the following statements

(i) Haemoglobin is 50% saturated at around 40 – 50 mmHg.
(ii) Maternal haemoglobin has greater affinity for O_2 as compared to foetal haemoglobin
(iii) Olfactory epithelium of nose is called Schneiderian membrane
(iv) The level of CO_2 has stronger effect on regulation of breathing as compared to O_2 level.

Which of these are correct?

(1) (i), (iii) & (iv)
(2) (ii) & (iii)
(3) (i), (ii) & (iii)
(4) (iii) & (iv)

143. O_2 dissociation curve is shifted to right in all except

(1) Hyper capnea
(2) Rise in temperature
(3) Raised 2.3 DPG level
(4) Metabolic alkalosis

144. It is dangerous to hold breath after prolonged hyperventilation because

(1) Lungs can collapse
(2) CO_2 narcosis
(3) Due to the lack of stimulation by CO_2 anoxia can come close to dangerous levels
(4) Decreased CO_2 shift the oxygen dissociation curve to the right

145. External respiration allows the exchange of carbon dioxide for oxygen at any altitude. Which of the following is not an adaptation to living high above the sea level?

(1) An increase in 2,3 BPG concentration, which shifts the O_2 dissociation curve to the right
(2) Increased production of red blood cells by the bone marrow
(3) Decreased synthesis of erythropoietin by the kidney
(4) Hyperventilation

146. Which of the following would be expected to have the greatest effect on the breathing effort?

(1) Slight change in venous carbon dioxide
(2) Large decrease in arterial oxygen

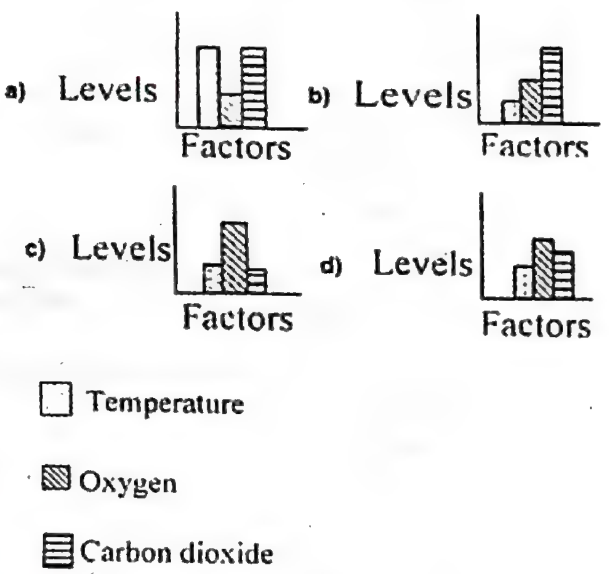
---

*139. FRC = ERV + RV. TLC = RV + ERV + IRV + TV.
*140. Vital capacity = 3.5 to 4.5 litres.
*141. The peripheral chemoreceptors are located in carotid arteries and arch of aorta. The chemosensitive area is highly sensitive to CO_2 and H^+.
*142. Hb is 50% saturated at 25 – 30 mm of Hg. FoetalHb has higher affinity for O_2 as compared to maternal Hb.

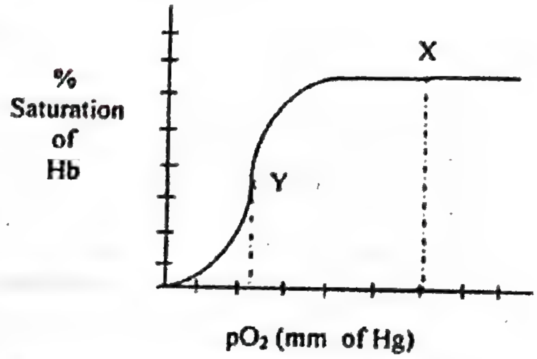
(3) Large increase in arterial carbon dioxide
(4) No change in hydrogen ion concentration

147. Which of the following statements correctly describes the respiratory tract?
I. The right lung is larger than the left
II. Expiration is predominantly a passive phenomenon
III. Air enters the lungs because of created negative pressure.
(1) I only (2) I and II only
(3) II and III only (4) I, II and III

148. Choose the combination of conditions in a tissue that would influence the most rapid dissociation of oxyhaemoglobin.

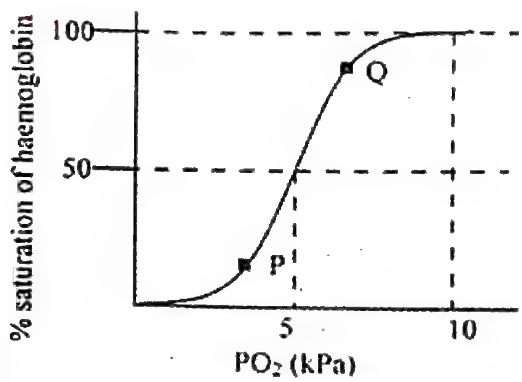


149. The accompanying graph depicts the % saturation of vertebrate haemoglobin with oxygen. What does X and Y indicate?



(1) X-oxygenated blood, Y-deoxygenated blood
(2) X-deoxygenated blood, Y-oxygenated blood
(3) X-blood of haemophilic person, Y-blood of normal person
(4) X-blood of foetus, Y-blood of adult

150. Oxygen saturation curve of haemoglobin molecule is shown in the graph.



The correct representation of haemoglobin molecule at points P and Q is respectively:
(1) HbO_2 and HbO_4
(2) HbCO and $HbCO_2$
(3) HbO_2 and HbO_8
(4) HbO_4 and HbO_6

*151. A person suffers punctures in his chest cavity in an accident, without any damage to the lungs its effect could be
(1) Reduced breathing rate
(2) Rapid increase in breathing rate
(3) No change in respiration
(4) Cessation of breathing

152. Mark the true statement among the following with reference to normal breathing
(1) Inspiration is a passive process where as expiration is active
(2) Inspiration is an active process where as expiration is passive
(3) Inspiration and expiration are active processes
(4) Inspiration and expiration are passive processes

*151. When there is a puncture wound as that in the question, the pleural cavity is exposed to the outer atmosphere. Normally there is always a negative pressure in the pleural cavity which helps to get the lungs inflated during inspiration. But in case of such an injury the air is sucked in towards the pleural cavity through the wound leading to pneumothorax and the lungs will collapse. Thus the best option is (4).

153. A person breathes in some volume of air by forced inspiration after having a forced expiration. This quantity of air taken in is
(1) Total lung capacity
(2) Tidal volume
(3) Vital capacity
(4) Inspiratory capacity

154. Respiratory process is regulated by certain specialised centres in the brain. One of the following listed centres can reduce the inspiration duration upon stimulation
(1) Medullary inspiratory centre
(2) Pneumotaxic centre
(3) Apneustic centre
(4) Chemosensitive centre

155. CO_2 dissociates from carbamino haemoglobin when
(1) pCO_2 is high & pO_2 is low
(2) pO_2 is high and pCO_2 is low
(3) pCO_2 and pO_2 are equal
(4) None of the above

156. Identify the correct and incorrect match about respiratory volume and capacities and mark the correct answer
(i) Inspiratory capacity (IC) = Tidal Volume + Residual Volume
(ii) Vital Capacity (VC) = Tidal Volume (TV) + Inspiratory Reserve Volume (IRV) + Expiratory Reserve Volume (ERV)
(iii) Residual Volume (RV) = Vital Capacity (VC) – Inspiratory Reserve Volume (IRV)
(iv) Tidal Volume (TV) = Inspiratory Capacity (IC) – Inspiratory Reserve Volume (IRV)

Options :
(1) (i) Incorrect, (ii) Incorrect, (iii) Incorrect (iv) Correct
(2) (i) Incorrect, (ii) Correct, (iii) Incorrect, (iv) Correct
(3) (i) Correct, (ii) Correct, (iii) Incorrect, (iv) Correct
(4) (i) Correct, (ii) Incorrect, (iii) Correct, (iv) Incorrect

157. When CO_2 concentration in blood increases, breathing becomes
(1) slow and deep
(2) faster and deeper
(3) shallower and slow
(4) there is no effect on breathing

158. Blood analysis of a patient reveals an unusually high quantity of carboxy-haemoglobin content. Which of the following conclusions is most likely to be correct?
The patient has been inhaling polluted air containing unusually high content of
(1) Carbon dioxide
(2) Carbon monoxide
(3) Carbon disulphide
(4) Chloroform

159. People living at sea level have around 5 million RBC per cubic millimeter of their blood whereas those living at an altitude of 5400 metres have around 8 million. This is because at high altitude.
(1) People get pollution-free air to breath and more oxygen is available
(2) Atmospheric O_2 level is less and hence more RBCs are needed to absorb the required amount of O_2 to survive
(3) There is more UV radiation which enhances RBC-production
(4) People eat more nutritive food, therefore more RBCs are formed

160. Which one of the following statements is incorrect?
(1) The residual air in lungs slightly decreases the efficiency of respiration in mammals
(2) The presence of non-respiratory air sacs, increases the efficiency of respiration in birds
(3) In insects, circulating body fluids serve to distribute oxygen to tissues
(4) The principle of countercurrent flow facilitates efficient respiration in gills of fishes

161. The majority of carbon dioxide produced by our body cells is transported to the lungs
(1) dissolved in the blood
(2) as bicarbonates
(3) as carbonates
(4) attached to hemoglobin

162. What is vital capacity of our lungs?
(1) Total lung capacity *minus* residual volume
(2) Inspiratory reserve volume *plus* tidal volume
(3) Total lung capacity *minus* expiratory reserve volume
(4) Inspiratory reserve volume *plus* expiratory reserve volume

163. The haemoglobin of a human foetus
(1) has a higher affinity for oxygen than that of an adult
(2) has a lower affinity for oxygen than that of the adult
(3) its affinity for oxygen is the same as that of an adult
(4) has only 2 protein subunits instead of 4.

164. The respiratory centre in medulla is sensitive to
(1) High CO_2 and high H^+ concentration
(2) Low O_2 concentration
(3) High O_2 concentration
(4) All of the above *(AIIMS – 2010)*

***165.** Listed below are four respiratory capacities (i – iv) and four jumbled respiratory volumes of a normal human adult

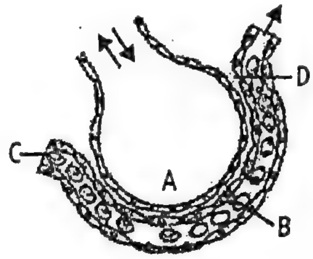
Respiratory capacities	Respiratory volumes
(i) Residual volume	2500 mL
(ii) Vital capacity	3500 mL
(iii) Inspiratory reserve volume	1200 mL
(iv) Inspiratory capacity	4500 mL

Which one of the following is the correct matching of two capacities and volumes?
(1) (i) 4500 mL (ii) 3500 mL
(2) (ii) 2500 mL (iii) 4500 mL
(3) (iii) 1200 mL (iv) 2500 mL
(4) (iv) 3500 mL (i) 1200 mL
(CBSE PRELIMS – 2010)

166. Which two of the following changes (i – iv) usually tend to occur in the plain dwellers when they move to high altitudes (3,500 m or more)?
(i) Increase in red blood cell size
(ii) Increase in red blood cell production
(iii) Increase breathing rate
(iv) Increase in thrombocyte count

Changes occurring are
(1) (i) and (ii) (2) (ii) and (iii)
(3) (iii) and (iv) (4) (i) and (iv)
(CBSE PRELIMS – 2010)

167. The figure given below shows a small part of human lung where exchange of gases takes place. In which one of the options given below, the one part A, B, C or D is correctly identified along with its function.



Options :
(1) C : arterial capillary – passes oxygen to tissues
(2) A : alveolar cavity – main site of exchange of respiratory gases
(3) D : Capillary wall – exchange of O_2 and CO_2 takes place here
(4) B : red blood cell – transport of CO_2 mainly *(CBSE PRELIMS – 2011)*

***168.** A large proportion of oxygen is left unused in the human blood even after its uptake by the body tissues. This O_2
(1) Acts as a reserve during muscular exercise
(2) Raises the pCO_2 of blood to 75mm of Hg.
(3) Is enough to keep oxyhaemoglobin saturation at 96%
(4) Helps in releasing more O_2 to the epithelial tissues. *(CBSE PRELIMS – 2011)*

***169.** Which one of the following is the correct statement for respiration in humans?
(1) Neural signals from pneumotoxic centre in pons region of brain can increase the duration of inspiration.
(2) Workers in grinding and stone–breaking industries may suffer, from lung fibrosis

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*165. Vital capacity varies from 3.5 to 4.5L. IRV is 2000 – 3000 mL.
*168. The percentage of blood that gives up its oxygen as it passes through the tissue capillaries is called the utilization coefficient. The normal value of this is 25 percent *i.e.,* 25% of the oxygenated haemoglobin gives its oxygen to the tissues. During stenuous exercise the utilization coefficient in the entire body can increase to 75 to 85% so that more oxygen is given to the tissues.
*169. Option (4) is also a correct answer as smoking causes chronic bronchitis. But as per NCERT (2) seems to be a better choice.

(3) About 90% of carbon dioxide (CO_2) is carried by haemoglobin as carbamino-haemoglobin

(4) Cigarette smoking may lead to inflammation of bronchi.

(CBSE PRELIMS – 2012)

170. People who have migrated from the planes to an area adjoining Rohtang Pass about six months back

(1) are not physically fit to play games like football

(2) suffer from altitude sickness with symptoms like nausea, fatigue, etc.

(3) have the usual RBC count but their haemoglobin has very high binding affinity to O_2

(4) have more RBCs and their haemoglobin has a lower binding affinity to O_2

(CBSE PRELIMS – 2012)

171. Which one of the following is a possibility for most of us in regard to breathing, by making a *conscious effort*?

(1) One can breathe out air totally without oxygen

(2) One can breathe out air through Eustachian tubes by closing both the nose and the mouth

(3) One can consciously breathe in and breathe out by moving the diaphragm alone, without moving the ribs at all.

(4) The lungs can be made fully empty by forcefully breathing out all air from them

(CBSE MAINS – 2011)

172. Bulk of carbon dioxide (CO_2) released from body tissues into the blood is present as

(1) bicarbonate in blood plasma and RBCs

(2) free CO_2 in blood plasma

(3) 70% carbamino-haemoglobin and 30% as bicarbonate

(4) carbamino-haemoglobin in RBCs

(CBSE MAINS – 2011)

173. Oxygen dissociation curve of haemoglobin is

(1) Sigmoid (2) Linear

(3) Hyperbolic

(4) Hypobolic

174. pH of blood in arteries and veins is

(1) More in veins less in arteries

(2) More in arteries less in veins

(3) Same

(4) No definite relation

175. The left lung of human is divided into

(1) One lobe (2) Two lobes

(3) Three lobes (4) Four lobes

(CHD. CET – 2011)

176. How much percent of O_2 is transported by RBCs in the blood?

(1) 3 percent (2) 97 percent

(3) 70 percent (4) 7 percent

(H.P. PMT – 2010)

177. What percent (%) of CO_2 is transported as bicarbonate (HCO_3) with the help of the enzyme carbonic anhydrase?

(1) 70% (2) 20-25%

(3) 97% (4) 7%

(H.P. PMT – 2011)

178. Muscle contains a red coloured oxygen storing pigment called

(1) Haemoglobin (2) Myoglobin

(3) Erythrocruorin (4) Hemolymph

(H.P. PMT – 2011)

179. Expiratory capacity of a person is the

(1) Tidal volume

(2) Expiratory reserve volume

(3) Residual volume

(4) Sum of tidal volume and expiratory reserve volume *(H.P. PMT – 2012)*

180. The urge to inhale in humans results from

(1) Rising PCO_2 (2) Rising PO_2

(3) Falling PCO_2 (4) Falling PO_2

(DUMET – 2010)

181. Wind pipe in man arises from

(1) Larynx (2) Nasopharynx

(3) Oropharynx (4) Laryngopharynx

(COMEDK's 2009)

182. A person is suffering from frequent episodes of nasal discharge, nasal congestion, reddening of eyes and watery eyes. These are the symptoms of

(1) bronchial carcinoma

(2) bronchitis

(3) rhinitis

(4) cyanosis *(K.CET 2009)*

183. The exchange of material between blood and interstitial fluid is by

(1) arteries (2) veins

(3) capillaries (4) arterioles

(Odisha 2009)

184. Oxygen carrying capacity of human blood is reduced due to the pollution of

(1) CO_2 (2) CO (3) SO_2 (4) O_3 *(AMU 2009)*

185. Hb value for a healthy adult male is
(1) 10g/100 ml (2) 11g/100ml
(3) 12g/100ml (4) 14–15g/100ml
(MHTCET 2009)

186. The exchange of gases between blood capillaries and alveoli in the lung is through
(1) simple diffusion (2) active transport
(3) osmosis (4) facilitated diffusion
(Odisha JEE 2010)

187. The factor which does not affect the rate of alveolar diffusion is
(1) solubility of gases
(2) thickness of the membranes
(3) pressure gradient
(4) concentration gradient
(5) reactivity of the gases
(Kerala PMT 2011)

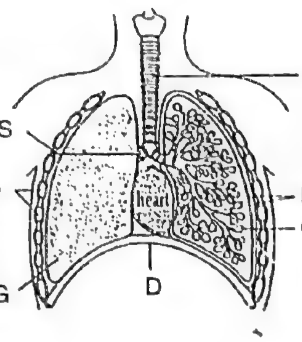
188. Pneumotaxic centre which can moderate the functions of the respiratory rhythm centre is present at
(1) pons region of brain
(2) thalamus
(3) spinal cord
(4) right cerebral hemisphere
(5) left cerebral hemisphere
(Kerala PMT 2011)

189. Hypoxia corresponds to
(1) any change in the relative rates of development of different cell lines in body
(2) hardening and loss of elasticity of arteries
(3) deficiency of oxygen in body tissues
(4) sudden interruption of blood flow to a portion of brain due to blockage of cerebral blood vessel *(Odisha JEE 2012)*

190. After forceful inspiration, the amount of air that can be breathed out by maximum forced expiration is equal to
(1) Inspiratory Reserve Volume (IRV) + Expiratory Reserve Volume (ERV) + Tidal Volume (TV) + Residual Volume (RV)
(2) IRV + RV + ERV
(3) IRV + TV + ERV
(4) TV + RV + ERV *(West Bengal JEE 2012)*

191. Choose the right sequential phenomena among the following during the delivery of O_2 from blood to tissue.
P : Absorption of CO_2 by the blood
Q : Reaction of absorbed CO_2 with H_2O to form H_2CO_3 within RBC and its conversion into H^+ and HCO_3^- ions
R : Reaction of absorbed CO_2 with H_2O in plasma to form H_2CO_3 and its conversion into H^+ and HC_3^- ions
S : Combination of H^+ with heme portion of HbO_2 to release O_2
T : Combination of HCO_3^- with heme portion HbO_2 to form reduced hemoglobin and release of O_2
(1) P, Q, T (2) P, R, S
(3) P, Q, S (4) P, R, T
(West Bengal JEE 2012)

192. The figure shows a diagrammatic view of human respiratory system with labels A, B, C and D. Select the option which gives correct identification and main function and/ or characteristic.



(1) C- Alveoli – thin walled vascular bag like structures for exchange of gases.
(2) D – Lower end of lungs-diaphragm pulls it down during inspiration.
(3) A- trachea –long tube supported by complete cartilaginous rings for conducting inspired air.
(4) B-pleural membrane –surrounds ribs on both sides to provide cushion against rubbing. *(NEET – 2013)*

193. Approximately seventy percent of carbon-dioxide absorbed by the blood will be transported to the lungs
(1) As carbamino-haemoglobin
(2) As bicarbonate ions
(3) In the form of dissolved gas molecules
(4) By binding to R.B.C. *(AIPMT 2014)*

194. Name the pulmonary disease in which alveolar surface area involved in gas exchange is drastically reduced due to damage in the alveolar walls.

(1) Pleurisy (2) Emphysema
(3) Pneumonia (4) Asthma
(AIPMT Retest 2015)

195. Name the chronic respiratory disorder caused mainly by cigarette smoking.
(1) Asthma
(2) Respiratory acidosis
(3) Respiratory alkalosis
(4) Emphysema *(AIPMT/NEET 2016)*

196. Reduction in *p*H of blood will
(1) reduce the blood supply to the brain
(2) decrease the affinity of hemoglobin with oxygen
(3) release bicarbonate ions by the liver
(4) reduce the rate of heart beat.
(AIPMT/NEET 2016)

197. The partial pressure of oxygen in the alveoli of the lungs is
(1) equal to that in the blood.
(2) more than that in the blood.
(3) less than that in the blood.
(4) less than that of carbon dioxide
(NEET-2-2016)

198. Lungs do not collapse between breaths and some air always remains in the lungs which can never be expelled because
(1) there is a negative pressure in the lungs
(2) there is a negative intrapleural pressure pulling at the lung walls
(3) there is a positive intrapleural pressure
(4) pressure in the lungs is higher than the atmospheric pressure
(NEET-2-2016)

199. Lungs are made up of air-filled sacs, the alveoli. They do not collapse even after forceful expiration because of
(1) residual Volume
(2) inspiratory Reserve Volume
(3) tidal Volume
(4) expiratory Reserve Volume
(NEET 2017)

ANSWERS

1. (2)	2. (2)	3. (3)	4. (3)	5. (1)	6. (2)	7. (3)	8. (4)	9. (2)	10. (1)
11. (2)	12. (2)	13. (1)	14. (1)	15. (3)	16. (1)	17. (2)	18. (2)	19. (1)	20. (2)
21. (2)	22. (3)	23. (3)	24. (2)	25. (2)	26. (3)	27. (4)	28. (2)	29. (4)	30. (4)
31. (3)	32. (2)	33. (3)	34. (2)	35. (4)	36. (1)	37. (4)	38. (2)	39. (2)	40. (1)
41. (3)	42. (3)	43. (3)	44. (4)	45. (2)	46. (1)	47. (3)	48. (3)	49. (2)	50. (1)
51. (1)	52. (2)	53. (4)	54. (1)	55. (2)	56. (3)	57. (2)	58. (3)	59. (3)	60. (2)
61. (4)	62. (2)	63. (1)	64. (1)	65. (2)	66. (4)	67. (2)	68. (1)	69. (1)	70. (4)
71. (4)	72. (3)	73. (3)	74. (2)	75. (1)	76. (2)	77. (4)	78. (4)	79. (1)	80. (4)
81. (3)	82. (3)	83. (1)	84. (1)	85. (3)	86. (3)	87. (1)	88. (2)	89. (1)	90. (4)
91. (4)	92. (1)	93. (1)	94. (3)	95. (3)	96. (1)	97. (3)	98. (3)	99. (3)	100. (3)
101. (3)	102. (4)	103. (1)	104. (3)	105. (2)	106. (1)	107. (4)	108. (2)	109. (1)	110. (2)
111. (3)	112. (1)	113. (4)	114. (4)	115. (2)	116. (4)	117. (3)	118. (4)	119. (4)	120. (4)
121. (1)	122. (4)	123. (4)	124. (2)	125. (1)	126. (1)	127. (2)	128. (2)	129. (2)	130. (4)
131. (2)	132. (4)	133. (1)	134. (3)	135. (1)	136. (1)	137. (2)	138. (1)	139. (4)	140. (3)
141. (2)	142. (4)	143. (4)	144. (3)	145. (3)	146. (3)	147. (4)	148. (1)	149. (1)	150. (3)
151. (4)	152. (2)	153. (3)	154. (2)	155. (2)	156. (2)	157. (2)	158. (2)	159. (2)	160. (3)
161. (2)	162. (1)	163. (1)	164. (1)	165. (4)	166. (2)	167. (2)	168. (1)	169. (2)	170. (4)
171. (3)	172. (1)	173. (1)	174. (2)	175. (2)	176. (2)	177. (1)	178. (2)	179. (4)	180. (1)
181. (1)	182. (3)	183. (3)	184. (2)	185. (4)	186. (1)	187. (5)	188. (1)	189. (3)	190. (3)
191. (3)	192. (1)	193. (2)	194. (2)	195. (4)	196. (2)	197. (2)	198. (2)	199. (1)	

Chapter

18

Body Fluids and Circulation

THEORY–a quick rundown

- **Body Fluids.** Body fluids are the medium of transport in the body. In the average 70 kg adult human total body water is about 60 percent of the body weight or about 42 litres.
- **Types of Body Fluids.** The total body fluid is of two types :

1. **Intracellular Fluid.** It is present inside the body cells. About 28 of the 42 litres of fluid in the body is inside the 75 trillion cells. The intracellular fluid contains large amount of potassium and phosphate ions and proteins, moderate quantities of magnesium and sulphate ions and only small quantities of sodium and chloride ions and almost no calcium ions. The most abundant intracellular cation is K^+.

2. **Extracellular Fluid.** All the fluids outside the cells are collectively called the extracellular fluid. It is about 14 litres in a normal 70 kg adult. The extracellular fluid is mainly present as interstitial fluid and blood plasma. The **interstitial fluid** (= **tissue fluid**) is about 11 litres and **plasma** contributes about 3 litres in a normal adult. Plasma includes **blood plasma** and **lymph plasma**. Lymph plasma is similar to the blood plasma except that lymph plasma has lower protein content. The interstitial fluid surrounds each cell. The plasma is the noncellular part of the blood and communicates continuously with the interstitial fluid through the pores of the capillary membranes. These pores are permeable to almost all solutes in the extracellular fluid except proteins.

Transcellular fluid is a specialized type of extracellular fluid. All the transcellular fluids together constitute about 1 to 2 litres. Transcellular fluid includes the following :

(i) **Cerebrospinal Fluid (CSF).** It is present inside the ventricles of the brain, the central canal of the spinal cord and in the subarachnoid space around the brain and spinal cord.

(ii) **Intraocular Fluid.** This fluid is found in the eye ball, *e.g.*, aqueous humour and vitreous humour.

(iii) **Serous Fluid.** Intrapleural fluid, pericardial fluid and peritoneal fluid are examples of serous fluid.

(iv) **Synovial Fluid.** It is present in the joints.

(v) **Digestive Fluid.** Digestive juices are the examples of digestive fluid.

(vi) **Fluid in Urinary Tract.** This fluid is present in the tract of excretory system.

BLOOD

fluid

Blood is a mobile connective tissue composed of a fluid, the plasma and the cells, the blood corpuscles. Blood is basis of life. Blood is the softest tissue in the body. The volume of blood in an adult person of 70 kg weight is about 5.5 litres. It is a slightly alkaline fluid having *pH 7.4.* pH of blood in arteries is more than in veins.

Blood is composed of a watery fluid called **plasma** and floating bodies termed **formed elements** (*e.g.*, blood corpuscles).

A. Plasma

It is slightly alkaline non-living intercellular substance which constitutes about 55% part of the blood. It is a pale yellow but transparent and clear fluid. Plasma's main constituents are the following

1. **Water.** Water alone forms about 90% to 92% of the plasma.
2. **Minerals.** These are Na^+, Ca^{++}, Mg^{++}, HCO_3^-, Cl^-, etc.
3. **Nutrients.** These include glucose, aminoacids, lipids, etc. Mineral salts have been mentioned above.
4. **Proteins.** They constitute about 6 to 8% part of plasma. These mainly include albumin for osmotic balance, globulin for defence mechanism and fibrinogen for blood clotting.
5. **Defence Compounds. Immunoglobulins** which act as antibodies and some other substances, such as **lysozyme** (a polysaccharide) and **properdin** (a large protein) are always found in the plasma. They destroy bacteria, viruses and toxic substances that may enter into the blood from outside.
6. **Excretory Substances.** These include ammonia, urea, uric acid, creatine, creatinine, etc.
7. **Dissolved Gases.** Water of blood plasma contains oxygen, carbon dioxide and nitrogen in dissolved form.
8. **Anticoagulant.** Blood plasma contains a conjugated polysaccharide, the **heparin** which prevents coagulation of blood inside blood vessels.
9. **Hormones.** These are secreted and released in blood by endocrine glands.
10. **Vitamins and Enzymes.** Different kinds of vitamins and enzymes are present in the blood plasma.
11. **Factors for clotting of blood.** These are also present in the plasma in an inactive form. Plasma without the clotting factors is called **serum.**

B. Formed Elements (Blood Corpuscles)

Formed elements or blood corpuscles are of the following three types : Erythrocytes, Leucocytes and Thrombocytes (Platelets). They constitute about 45% of the blood.

1. Erythrocytes (Red Blood Corpuscles or RBCs)

They are the most abundant cells in the human body. The total number of RBCs per microlitre of blood is termed as the **total count of RBCs**. A healthy adult man has on an average 5 to 5.5 million RBCs per cubic millimetre of blood. The total count of RBCs is more in man than in a woman. It is due to the fact that women undergo menstruation. Less amount of haemoglobin leads to **anaemia.** Anaemia may be caused by loss of blood (haemorrhage), destruction of RBCs (haemolysis or faulty formation of blood). The increase in number of RBCs may be during muscular exercise to meet the increased demand of oxygen and at high altitudes to cope with the low oxygen content of the air. An abnormal rise in RBC count in called **polycythemia.** Descrease in the number of RBCs is called **erythrocytopenia** which causes oxygen shortage in the blood and tissues. It is important to note

that the oxygen shortage stimulates the kidney cells to secrete a hormone named **erythropoietin**, into the blood. Erythropoietin stimulates the bone marrow to increase the production of RBCs.

Red blood corpuscles of all adult mammals are **enucleated** (non-nucleated). They are mostly biconcave and circular, however in camal and Llama (American animal) RBCs are oval. Biconcave form of human RBCs is advantageous in gas exchange because biconcave disc has more surface area than a sphere.

Human erythrocytes are 7–8 μm in diameter and 1–2 μm thick near the rim. The RBCs look yellowish when seen singly and red when viewed in bulk. They impart red colour to the blood. Red colour is due to the presence of haemoglobin.

Matured mammalian RBCs do not have cell organelles including nucleus, Golgi bodies, mitochondria, ribosomes, centrioles and endoplasmic reticulum. It increases the surface area of RBCs and enables these to contain more haemoglobin. Thus almost entire cytoplasm is filled with **haemoglobin**. In the absence of cell organelles, the consumption of oxygen is very low. Anaerobic respiration occurs in RBCs. Haemoglobin is a conjugated protein which is made up of a protein called **globin** and a non protein group **heme** (= haeme), hence the name haemoglobin. Heme is an iron (Fe^{++})– porphyrin complex. A mammalian haemoglobin molecule is complex of 4 heme molecules joined with 4 globin molecules. A red blood corpuscle has some 280 million haemoglobin molecules. Haemoglobin is the oxygen carrying pigment. 100 ml of blood of a healthy individual contains about 12-16 gms of haemoglobin. The quantity of haemoglobin is less in women as they undergo menstruation.

Formation of erythrocytes is called **erythropoiesis.** In the early few weeks of embryonic life, primitive nucleated RBCs are produced in the **yolk sac.** (one of the embryonic membranes). In later embryonic stage, RBCs are mainly produced by the liver and spleen. But from birth onwards, RBCs are produced by bone marrow. **Hemocytoblasts** in red bone marrow give rise to mature RBCs. Iron and proteins are necessary raw materials for the synthesis of haemoglobin. However vitamin B_{12} and folic acid stimulate the maturation of RBCs. Thus iron, protein, vitamin B_{12} and folic acid are essential for the formation of haemoglobin and RBCs. Deficiency of any of these nutrients can cause anaemia. Excess RBCs are stored in the spleen.

The life of a RBC is about 120 days after which they are destroyed in the spleen which is called graveyard of RBCs.

RBCs perform the following functions : (i) Transport of O_2. (ii) Transport of CO_2 and (iii) Maintenance of pH of blood.

2. **Leucocytes (WBCs).** They are colourless due to the lack of haemoglobin. They are nucleated and are relatively lesser in number which averages 6000—8000 mm^{-3} of blood. WBCs are generally short lived. The leucocytes are of two types : Agranulocytes and Granulocytes. Agranulocytes include lymphocytes and monocytes. Granulocytes are eosinophils, basophils and neutrophils.

8 – 16 μm

Differences between different types of Leucocytes

Characters	*Lymphocytes*	*Monocytes*	*Eosinophils (Acidophils)*	*Basophils*	*Neutrophils*
Percentage in total leucocytes	20-25%	2-8%	2-3%	0.5-1%	60-65%
Granules in cytoplasm	Absent	Absent	Coarse	Coarse	Fine

Nucleus	Rounded	Bean-shaped	Bilobed	S-shaped	Multilobed
Formation	Lymphnodes	Bone marrow spleen, thymus, tonsils and Payer's patches	Bone marrow	Bone marrow	Bone marrow
Life span	3-10 days Few days or even years memory cells → years	10-12 hours in the blood tissue, months or even years	14 hours	8-12 hours	10-12 hours
Functions	Two major types B and T lymphocytes both are responsible for immune responses of the body	Phagocytic	Important role in immunity antiallergic	Secretion of heparin, histamine and serotonin and are involved in inflammatory reactions	Phagocytic

The ratio of WBC : RBC in our blood is 1 : 600. **Leucocytosis**— Rise in WBC count. **Leukemia** (Blood Cancer)— abnormal increase of WBCs. **Leukopenia**— Fall in WBC count.

3. **Thrombocytes (Blood platelets).** These are really cell fragments rather than true cells. They are non nucleated, round or oval, biconvex disc-like bodies. In fact they bud off from **megakaryocytes** (very large cells formed by the bone marrow). They are 2-3 micrometres in diameter and are much smaller than both the red and white blood corpuscles. Blood normally contains 1,500,00—3,500,00 platelets mm^{-3}. When any injury is caused, the blood platelets release certain chemicals which are termed the **platelet factors** (*e.g.*, thromboplastin) which help in the coagulation of blood. Normal life span of blood platelets is about a week. A decrease in their number can lead to clotting disorders.

Spindle Cells. These occur in all vertebrates other than mammals. Their function is similar to that of mammalian blood platelets.

Blood Groups

There are more than 30 antigens on the surface of blood cells that give rise to different blood groups. In a blood transfusion, certain blood groups, *e.g.*, ABO blood group, of the recipient and donor must be matched, otherwise the recipient's immune system will produce antibodies that cause agglutination of the transfused cells and block blood circulation through capillaries. Two types of blood groups— ABO Blood Group and Rh Blood Group (Rh Factor) are widely used all over the world.

ABO Blood Groups. **Karl Landsteiner** reported first time ABO blood groups in human beings. A, B and O blood groups were discovered by Landsteiner (1900) while AB blood group was found out by **de Castello** and **Steini** (1902). ABO blood groups are determined by the gene I (isoagglutinin). There are three alleles, I^A, I^B and I^O of this gene. Proteins produced by the I^A and I^B alleles are called A antigen and B antigen. People with blood group A have the A antigen on the surface of their RBCs, and antibodies in their plasma. Persons with blood group B have B antigen on their RBCs, and antibodies in their plasma. Individuals with AB blood group have both antigen A and antigen B on their RBCs, and no antibodies in their plasma. Type O individuals are without A and B antigens on their RBCs, but have antibodies in their plasma. Individuals with blood group AB can receive blood of A, B or O group, while those with blood group O can donate blood to anyone. This is the most important

blood group for transfusion. Thus person with blood group AB is called universal recipient and person with blood group O is called universal donor. If a blood transfusion is made between an incompatible donor and recipient, reaction of antigens on the cells and antibodies in the plasma produces clots that clog capillaries.

Human ABO Blood groups and their compatibility

Blood group	Genotype	Antigens in red Blood Corpuscles	Antibodies in Blood plasma	Can give blood to	Can get blood from
A	I^AI^A or I^AI^O	A	b	A, AB	A, O
B	I^BI^B or I^BI^O	B	a	B, AB	B, O
AB	I^AI^B	AB	None	AB	All
O	I^OI^O	None	a, b	All	O

Rh (Rhesus) Blood Group (Rh Factor). A protein named as **rhesus antigen,** is present on the surface of red blood corpuscles in many persons. It was discovered in 1940 by Landsteiner and Wiener in the blood of **Rhesus** monkey, hence its name. Depending on the race, 85 to 99 percent of the white population have this rhesus antigen (also called Rh factor) and are called Rh positive (Rh^+). Others who do not have this factor are known as *Rh negative* (Rh^-). Rh^+ is dominant to Rh^-. Whites Rh^+ 85%, Rh^- 15%, American Blacks Rh^+ 95%, Rh^- 5%, African Blacks Rh^+ 100%.

Formation of Rh protein is controlled by a dominant gene which may be called as R. Thus, RR (homozygous) and Rr (heterozygous) persons are dominant and are Rh positive and rr (homozygous) are recessive and are Rh^- negative. Both Rh^+ and Rh^- individuals are phenotypically normal. The problem arises during blood transfusion and pregnancy.

(i) **Incompatibility during Blood Transfusion.** The first blood transfusion of Rh^- blood to the person with Rh^- blood causes no harm because the Rh^- person develops **anti Rh factors or antibodies** in his/her blood. In second blood transfusion of Rh^+ blood to the Rh^- person, the latter's anti Rh factors attack and destroy the red blood corpuscles of the donor.

(ii) **Incompatiblity during Pregnancy.** If father's blood is Rh^+ and mother's blood is Rh^-, the foetus' (baby in the uterus) blood is Rh^+. This is a serious problem. If the Rh^- blood of mother has not earlier come in contact with Rh^+ blood through transfusion, her first child does not suffer (although the Rh^+ blood of the foetus stimulates the formation of anti Rh factors or antibodies in the mother's blood yet enough anti Rh factors are not produced in the mother's blood to harm the foetus). But in the subsequent Rh^+ foetuses, the anti Rh factors (antibodies) of the mother's blood destroy the foetal red blood corpuscles. This results in **haemolytic disease of the newborn** (HDN). It is called **erythroblastosis foetalis** (destruction of the erythrocytes of foetus). Newborn may survive but it is often anaemic. In order to prevent HDN, Rh^- mothers are injected with a defective anti Rh-antibody during all pregnancies carrying Rh^+ foetus. Rh^- mother and Rh^+ father is not recommended. Rh^+ is dominant.

Coagulation of Blood (= Blood Clotting)

When an injury is caused to a blood vessel bleeding starts which is stopped by a process called **blood clotting** or **blood coagulation**. This process can be described under three major steps.

(i) At the site of an injury, the blood platelets disintegrate and release a phospholipid, called **platelet factor-3** (= Platelet thromboplastin). Injured tissues also release a lipoprotein factor called **thromboplastin**. These two factors combine with calcium ions (Ca^{++}) and certain proteins of the blood plasma to form an enzyme called **pro-thrombinase.**

(ii) The prothrombinase inactivates **heparin** (or **antiprothrombin-anticoagulant**) in the

presence of calcium. **Prothrombinase** catalyzes breakdown of **prothrombin** (inactive plasma protein) into an active protein called **thrombin** and some small **peptide fragments**.

(iii) Thrombin acts as enzyme and first brings about depolymerization of **fibrinogen** (a soluble plasma protein) into its monomers. Later thrombin stimulates repolymerization of these monomers into long insoluble fibre-like polymers called **fibrin**. The thin, long and solid fibres of fibrin form a dense network upon the wound and trap blood corpuscles (RBCs, WBCs and platelets) to form a **clot**. The clot seals the wound and stops bleeding. Soon after the clot starts contracting and a pale yellow fluid, the **serum** , starts oozing out. This serum is blood plasma minus fibrinogen and blood corpuscles.

Vitamin K is essential for blood clotting as it is necessary for the synthesis of prothrombin in the liver.

Bleeding Time

In the clotting mechanism pathways thrombin activates factors XI, VIII, V. Bleeding time is 3 to 6 minutes.

Clotting Time

The normal clotting time is about 3 to 8 minutes.

Recent theory of blood clotting is **cascade theory** proposed by **Macferlane**. According to this theory 13 factors are required for blood clotting. VI factor is hypothetical. Actually there is no factor VI.

Table 18.1. Clotting factors in the blood and their synonyms.

Clotting Factor	Synonyms
I	Fibrinogen
II	Prothrombin
III	Thromboplastin
IV	Calcium
V	Proaccelerin, labile factor, accelerator globin (ACG)
VII	Proconvertin, Serum prothrombin conversion accelerator (SPCA), stable factor
VIII	Antihaemophilic factor (AHF), antihaemophilic factor A, Antihaemophilic globulin (AHG)
IX	Plasma thromboplastin component (PTC); Christmas factor, Antihaemophilic factor B
X	Stuart-Prower factor
XI	Plasma thromboplastin antecedent (PTA), antihaemophilic factor C
XII	Hageman factor, glass factor
XIII	Fibrin– stabilizing factor (FSF), Laki-Lorand factor

In the extrinsic clotting pathway the active factor VII activates factors IX and X.

Lymph (Tissue Fluid)

Lymph is a mobile connective tissue comprising lymph plasma (fluid) and lymph corpuscles (cells).

Lymph plasma is similar to that of blood but has fewer blood proteins, less calcium and phosphorus and high glucose concentration. Mainly globulin proteins are present which are actually

antibodies. Other components of the lymph plasma are very much like that of blood plasma, *i.e.*, organic, inorganic substances, water, etc.

Lymph corpuscles are floating amoeboid cells, the leucocytes (white blood corpuscles), which are mostly lymphocytes. Erythrocytes (red blood corpuscles) and platelets are absent in lymph.

The organs which secrete lymph are called **lymphoid organs**. Besides the lymph nodes, tonsils, thymus gland, spleen and Peyer's patches are the other lymphoidal organs. *The spleen is the largest mass of lymphatic tissue in the body.*

Lymph performs the following functions :— (i) Lymph acts as a "middle man" which transports oxygen, food materials, hormones, etc., to the body cells and brings carbon dioxide and other metabolic wastes, from the body cells to blood and then finally pours the same into the venous system. (ii) Body cells are kept moist by the lymph. (iii) Lymph nodes produce lymphocytes. Lymph takes lymphocytes and antibodies from the lymph nodes to the blood. (iv) It destroys the invading microorganisms and foreign particles in the lymph nodes. (v) It absorbs and transports fat and fat soluble vitamins from the intestine. Lymphatic capillaries present in the intestinal villi are called **lacteals** which are associated with absorption and transportation of fat and fat soluble vitamins. (vi) It brings plasma protein macromolecules synthesized in the liver cells and hormones produced in the endocrine glands to the blood. These molecules can not pass into the narrow blood capillaries but can diffuse into the lymphatic capillaries. (vii) Lymph maintains the volume of the blood. As soon as the volume of the blood reduces in the blood vascular system, the lymph rushes from the lymphatic system to the blood vascular system.

Circulatory Pathways

The circulatory patterns are of two types— open or closed.

1. **Open Circulatory System.** When the blood does not remain confined to the blood vessels and flows into spaces called **sinuses** in the tissues, it is termed as the open circulatory system. Invertebrate animals that have open circulatory system are the **arthropods** (such as prawns, crabs, lobsters, insects and spiders) and most of the **molluscs** (such as snails, oysters and clams). In insects like cockroach, the body cavity is filled with blood, the **haemolymph** (colourless blood), that is why it is called **haemocoel**.

2. **Closed Circulatory System.** When the blood remains confined to the blood vessels it is called the closed circulatory system. Invertebrate animals with a closed circulatory system are some **annelids** (such as the earthworm) and some molluscs (such as squid). All vertebrate animals have closed circulatory system. The circulation of blood in the closed circulatory system was first disocovered and demonstrated by **William Harvey** (1578–1657).

All vertebrates have a muscular chambered heart.

(i) Fishes have a 2-chambered heart with an atrium and a ventricle. In fishes deoxygenated blood from heart → gills where blood is oxygenated → from gills oxygenated blood → body parts → deoxygenated blood from body parts → heart **(single circulation)**.

(ii) Lung Fishes, amphibians and reptiles (except crocodiles) have 3-chambered heart with two atria and single ventricle. The left atrium receives oxygenated blood from the gills/lungs/skin and right atrium receives deoxygenated blood from the body parts. Both oxygenated and deoxygenated blood get mixed up in the single ventricle which pumps out mixed blood **(incomplete double circulation)**.

(iii) Crocodiles, birds and mammals have a 4-chambered heart with two atria and two ventricles.

(iv) In birds and mammals oxygenated blood → left atrium → left ventricle → different body parts. Deoxygenated blood → right atrium → right ventricle → lungs. There is no mixing of blood in the ventricle. Two separate circulatory pathways are present. Thus these animals have **double circulation**.

Let us study the human circulatory system.

HUMAN CIRCULATORY SYSTEM

Human Heart

Human heart is located between the lungs in the thoracic cavity. An average adult heart is about 12 cm in length. Its weight varies in males from 280–340 g (average 300 g) and in females from 230–280 g (average 250 g). Weight of the heart is said to be about 0.45% of body weight in males and 0.40% in females. Adult weight is achieved between 17–20 years.

Pericardium is a two layered sac consisting of outer **parietal pericardium** and inner **visceral pericardium**. In between the two layers, a space, the **pericardial cavity** is present which is filled with a **pericardial fluid**. The pericardium protects the heart from shocks and mechanical injuries and also allows free movements of the heart.

Structure of Human Heart. The **superior vena cava** carries blood from the body's upper region. The **inferior vena cava** carries blood from the lower body's region. The **coronary sinus** carries the majority of blood from the heart itself. The coronary veins open into the coronary sinus. The right atrium receives deoxygenated blood. The left atrium receives oxygenated blood from the lungs through two pairs of **pulmonary veins.** The pulmonary trunk arises from the right ventricle. It divides into left and right pulmonary arteries that carry deoxygenated blood to the lungs. The aorta arises from the left ventricle. The **right** and **left coronary arteries** arise from the ascending aorta. The arch of the aorta (also called aortic arch) gives rise to the **brachiocephalic artery** (Innominate artery), **left common carotid artery** and **left subclavian artery**.

The pulmonary trunk is connected with the aorta by the **ligamentum arteriosum** that represents the remnant of an embryonic connection between the pulmonary trunk and aorta. In the embryo, the ligamentum arteriosum is called **ductus arteriosus**.

The opening of inferior vena cava is guarded by **Eustachian valve.** The opening of the coronary sinus has **coronary** or **Thebasian valve.** In the right atrium adjoining the interatrial septum, an oval depression, the **fossa ovalis** is present. It marks the position of an opening, the **foramen ovale**, between the two atria in the foetus, but in the adult it persists only as a depression. The left atrium receives four openings of pulmonary veins. The artrioventricular opening between the left atrium and the left ventricle is guarded by the **bicuspid valve**, also called **mitral valve** (having two flaps). The right atrio-ventricular opening is guarded by the **tricuspid valve**, as it has three flaps. Attached to the flaps of the bicuspid and tricuspid valves are special fibrous cords, the **chordae tendineae,** which are joined to the other ends with the special muscles of the ventricular wall, the **papillary muscles.** The columnae carneae divide the cavity of the ventricles into smaller spaces, known as **fissures.** At the base of the pulmonary trunk and aorta are located three half-moon shaped pockets known as **semilunar valves.**

The wall of the heart consists of an outermost **visceral pericardium,** the middle thick muscular layer— the **myocardium,** and the innermost layer, the **endothelium** consisting of simple squamous epithelial cells.

Working of Human Heart. A contraction of the heart is called **a systole** and its relaxation a **diastole.** The right atrium receives de-oxygenated blood from different parts of the body and the muscular walls of the heart itself through the openings of superior vena cava, inferior vena cava and coronary sinus respectively. The left atrium receives oxygenated blood from the lungs through the openings of the pulmonary veins. The de-oxygenated and oxygenated bloods are forced into their respective ventricles through atrioventricular openings by the contraction of the atria. The contraction of atria is initiated and activated by the **sinoatrial node (SAN—pace maker)** which spreads waves

of contraction across the walls of the atria via muscle fibres at regular intervals. When the wave of contraction originating from the sinoatrial node reaches the **atrio-ventricular node (AVN— pace setter)**, the latter is stimulated and excitatory impulses are rapidly transmitted from it to all parts of the ventricles via **bundle of His** and **Purkinje's fibres.** These impulses stimulate the ventricles to contract simultaneously. The ventricles force blood through long system of arteries and hence must exert great pressure on the blood.

How the heart is nourished ?

The two coronary arteries arise from the aorta and pass throughout the heart muscles and ultimately form capillaries which give rich supply of blood to the wall of the heart. This capillary network pours its blood into the coronary veins which lead into the coronary sinus and the latter empties vessels into the right atrium.

Heart Beat

Heart beat is the rhythmic contraction and relaxation of the heart. Each heart beat includes one systole (contraction phase) and one diastole (relaxation phase) of the heart to distribute and receive blood to and from the body. The heart of a healthy person beats 70-75 times per minute (average 72 beats per minute).

Because smaller animals have the higher metabolic rate, their heart rate is higher than larger animals. An elephant has normal heart rate of about 25 per minute whereas mouse has a normal heart rate of several hundreds per minute.

Types. The heart beat is of two types : **neurogenic** and **myogenic.** The neurogenic heart beat is initiated by a nerve impulse coming from a nerve ganglion (mass of nerve cells) situated near the heart. It is present in the heart of some annelids and most arthropods. The myogenic heart beat is initiated by a patch of modified heart muscle itself. It is found in hearts of molluscs and vertebrates including human being.

Origin of heart beat. The mammalian heart is myogenic (*myo* = muscle, *genic* = originating from). It means the heart beat originates from a muscle, (however, it is regulated by the nerves). The heart beat originates from the **sinoatrial node** (SA Node)— **pace maker,** which lies in the wall of the right atrium near the opening of the superior vena cava. The SA node is a mass of neuromuscular tissue.

Conduction of heart beat. Another mass of neuromuscular tissue, the **atrio-ventricular node** (AV node) is situated in the wall of the right atrium. The AV node picks up the wave of contraction propagated by SA node. A mass of specialized fibres, the **bundle of His**, originates from the AV node. The bundle of His divides into two branches, one going to each ventricle. Within the mycocardium of the ventricles the branches of bundle of His divide into a net work of fine fibres called the **Purkinje fibres**. The bundle of His and the Purkinje fibres convey impulse of contraction from the AV node to the myocardium of the ventricles.

Regulation Of Cardiac Activity

(i) **Nervous Regulation.** The sympathetic nerves (part of ANS) increase the rate of heart beat. The parasympathetic nerve fibres (another component of ANS) decrease the rate of heart beat. These parasympathetic nerve fibres travel through vagus (X) cranial nerve.

(ii) **Hormonal Regulation.** **Adrenalin** (epinephrine) and **noradrenalin** (norepinephrine) hormones are secreted by the medulla of the adrenal glands. Noradrenalin accelerates the heart beat under normal conditions while adrenalin does this function at the time of emergency. These hormones directly influence the SA node.

Thyroxine hormone secreted by thyroid gland increases oxidative metabolism of the body cells. This requires more oxygen and thus indirectly increases heart beat.

The amount of blood pumped by heart per minute is called **cardiac output**. Heart of a normal person beats 72 times per minute and pumps out about 70 millilitres of blood per beat. Thus the cardiac output is 72 × 70 or 5040 milliliters per minute *i.e.*, about 5 litres per minute which is equivalent to the total body blood volume (about 5.5 litres).

Pulse is the rhythmic contraction and relaxation in the aorta and its main arteries. Thus pulse is a wave of increase which passes through arteries as the left ventricle pumps its blood into the aorta. Pulse is a regular jerk of an artery. Therefore, it is also called **arterial pulse**. The pulse rate is exactly the same as the heart rate because an artery pulses every time the heart beats. Pulse is usually taken on the **radial artery** in the wrist but it can be taken on any artery that flows near enough to the surface of the body to be felt.

The **factors** which affect the pulse rate are as follows : (i) The pulse rate in children is more rapid than in adults. (ii) The pulse rate is more rapid in the female than in the male. (iii) When the person is standing up the pulse rate is more rapid than when he/she is lying down. (iv) When any strong emotion is experienced the pulse rate is increased, for example, anger, excitement, fear, etc. (v) Any exercise increases the rate of the pulse.

Cardiac Cycle

The cardiac cycle consists of one heart beat or one cycle of contraction and relaxation of the cardiac muscle. During a heart beat there is contraction and relaxation of atria and ventricles. The contraction phase is called the systole while the relaxation phase is called the diastole. When both the atria and ventricles are in diastolic or relaxed phase, this is referred to as a **joint diastole**. The successive stages of the cardiac cycle are briefly described below. (a) **Atrial systole**. The atria contract due to a wave of contraction, stimulated by the SA node. The blood is forced into the ventricles as the bicuspid and tricuspid valves are open. (b) **Beginning of ventricular systole**. The ventricles begin to contract due to a wave of contraction, stimulated by the AV node. The bicuspid and tricuspid valves close immediately producing part of the **first heart sound**. (c) **Complete ventricular systole.** When the ventricles complete their contraction, the blood flows into the pulmonary trunk and aorta as the semilunar valves open. (d) **Beginning of ventricular diastole**. The ventricles relax and the semilunar valves are closed. This causes the **second heart sound.** (e) **Complete ventricular diastole**. The tricuspid and bicuspid valves open when the pressure in the ventricles falls and blood flows from the atria into the ventricles. Contraction of the heart does not cause this blood flow. It is due to the fact that the pressure within the relaxed ventricles is less than that in the atria and veins. The duration of a cardiac cycle is 0.8 sec.

Heart Sounds. The beating heart produces characteristic sounds which can be heard by placing the ear against the chest or by using **stethoscope** (an instrument which magnifies sounds and conducts them to ear). In a normal person, two sounds are produced per heart beat. (i) **First sound.** This is caused partly by the closure of the bicuspid and tricuspid valves and partly by the contraction of the muscles in the ventricles. The first sound, ***'lubb'*** is *low pitched*, not very loud and of long duration. (ii) **Second sound.** This is caused by the closure of the semilunar valves and marks the end of ventricular systole. The second sound **'dup'** is *highly pitched*, louder, sharper and shorter in duration. The two sounds have been described in words as "*lubb dup*" and their quality indicates the state of the valves. Damage to the bicuspid or tricuspid valve effects the quality of the first heart sound. When the semilunar valves are injured, a soft hissing noise "*lubb shhh*" is heard in place of the second sound. This is called a **heart murmur.** It may be caused by the syphilis, rheumatic fever or any other disease which injures the semilunar valves and affects their working. Thus, the blood can leak back from the pulmonary trunk and aorta into the ventricles.

The automatic rhythmicity of the heart is its ability to contract spontaneously and at a regular rate. Although the origin of cardiac impulse is **myogenic**, the rate of its formation and conduction may be changed by the action of nerves. For example, the sympathetic nerve fibres increase the activity of the SA node to accelerate the heart beat while the vagus 10th cranial nerve (carries para-sympathetic nerve fibres) decreases the rate of impulse formation from the SA node and its conduction. AV node, bundle of His and Purkinge fibres together provide autorhythmicity to the heart.

Blood Pressure (BP)

Blood pressure does not mean a disease at all. It is essential for life and every person has blood pressure to a certain degree. The pressure exerted by the flow of blood on the elastic walls of the arteries is called blood pressure. The blood pressure is greater during the *systole* than during the *diastole*. The blood pressure is measured by the use of **sphygmomanometer** (invented in Italy in 1896 by **Dr. Scipione Riva-Rocci**). In normal young person, the **systolic pressure** is 120 mm Hg and **diastolic pressure** is 80mm Hg. It is normally expressed as 120/80. The blood pressure varies with age. It is influenced by the rate of heart beat. Normal heart beats of a man are 72 per minute.

A persistent rise in blood pressure is called high blood pressure or **hypertension**. Fall in BP is termed as low blood pressure or **hypotension**.

Electrocardiogram (ECG)

ECG is a graphic record of the electric current produced by the excitation of the cardiac muslces. **Waller** (1887) first recorded the electrocardiogram but **Einthoven** (1903) studied ECG in details, therefore, he got Nobel Prize in 1924 for discovery of ECG. He is also considered "father of electrocardiography" (the device used).

A normal electrograph (ECG) is composed of a **P wave**, a **QRS wave (complex)** and a **T wave**. The letters are arbitrarily selected and do not stand for any particular words.

1. The **P wave** indicates the *atrial contraction*.
2. The **QRS wave (complex)** represents *ventricular contraction*
3. The **T wave** indicates *Ventricular relaxation*.

The enlarged Q and R waves indicate a myocardial infarction (heart attack).

T wave is flat when the heart muscle receives insufficient oxygen as in atherosclerotic heart disease. It may be elevated when the body's potassium level is increased.

The importance of ECG is that it gives accurate information about the heart. Therefore, ECG is of great diagnostic value in cardiac diseases.

Pacemaker

SA node is called the **natural pacemaker.** When SA node does not send impulses to the atria, the ventricles fail to receive atrial impulses. The conducting system of the heart is disrupted. In such patients normal heart beat can be restored and maintained with an **artificial pacemaker**. The artificial pace maker was introduced by **Chardack** in 1960.

Temporary pacemaker is used in emergency such as arrythmia control (*e.g.*, bradycardia – slow heart beat).

Permanent pacemaker is used in atrioventricular (AV) block, SA node dysfunction, etc. In the patients of **Stokes adams syndrome (ventricular escape** or **ventricular asystole)** atrial impulse suddenly fails to be transmitted to the ventricles. In such patients, the permanent pacemaker is implanted.

An artificial pacemaker is an artificial electronic device which regularly sends small amount of electrical charges that stimulate the heart. The artificial pacemaker consists of (a) a **pulse–generator** containing cell (solid state lithium cell) to produce electrical impulse, (b) the **lead** in the form of a

wire which transmits the impulse and (c) an **electrode**, which is connected to the portion of the heart where impulse is to be transmitted.

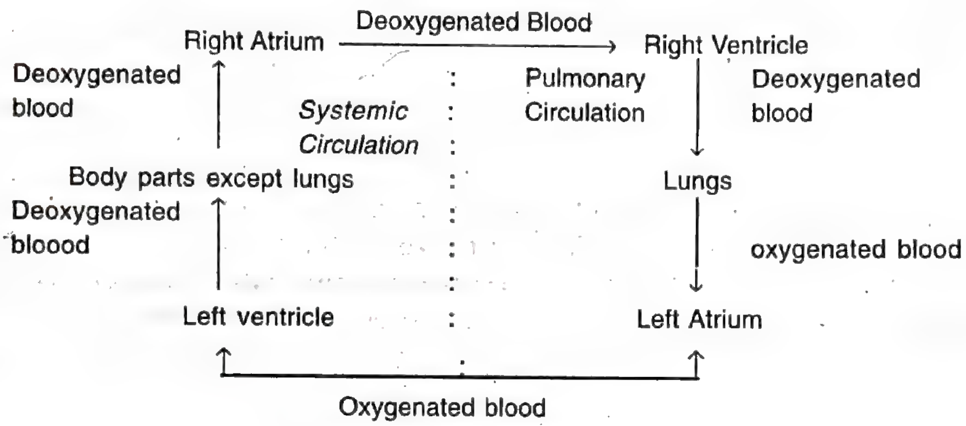
Double Circulation

Systemic circulation and pulmonary circulation constitute the double circulation.

1. **Systemic circulation.** It is the flow of blood from the left ventricle to all parts of the body and back to the right atrium. The purpose of systemic circulation is to carry oxygen and nutrients to body tisues and to remove carbon dioxide and other wastes from the tissues.

All systemic arteries arise from the **aorta** which originates from the left ventricle of the heart.

Blood is returned to the heart through the systemic veins. All the veins of the systemic circulation open into either the **superior vena cava** or **inferior vena cava** or **coronary sinus**. They in turn carry blood into the right atrium.



Double Circulation

2. **Pulmonary circulation.** The flow of deoxygenated blood from the right ventricle to the lungs and the return of oxygenated blood from the lungs to the left atrium is called the **pulmonary circulation.** The **pulmonary trunk** arises from the right ventricle and then divided into the **right pulmonary artery** and **left pulmonary artery** which supply deoxygenated blood to the right and left lungs respectively, where exchange of gases takes place. Two **pulmonary veins** from each lung transport the oxygenated blood to the left atrium.

Coronary Circulation

The flow of oxygenated blood from the ascending aorta to the heart muscle and the return of deoxygenated blood from the heart muscle to the right atrium is called **coronary (cardiac) circulation**. The **right** and **left coronary arteries** arise from the ascending aorta which supply oxygenated blood to the heart muscle (myocardium). The **coronary veins** bring deoxygenated blood to the **coronary sinus.** The latter carries deoxygenated blood to the right atrium.

Hepatic Portal Circulation (Hepatic Portal System)

Blood enters the liver from two sources. The hepatic artery supplies oxygenated blood from the thoracic aorta and the hepatic portal vein carries deoxygenated blood from the digestive organs. The flow of deoxygenated blood from the digestive organs to the liver before returning to the heart is called **hepatic portal circulation.**

A vein which does not carry blood directly to the heart but forms a network of capillaries in another or intermediate organ before reaching the heart is called a **portal vein.** A portal vein together with small veins from which it receives blood is called the **portal system.** A portal system is named

after the organ to which it carries blood. The vertebrates possess two or three portal systems. These are hepatic portal, renal portal and hypophysial portal systems. Renal portal system is absent in human beings.

Hepatic portal system is present in all the vertebrates including man. It brings blood from the alimentary canal, pancreas and spleen to the liver hence it is named as hepatic portal system.

The hepatic portal system includes a large **hepatic portal vein** and a number of other veins which collect blood from different parts of the alimentary canal and its associated structures.

Importance of Hepatic Portal System. (i) The blood which comes from the alimentary canal contains absorbed food like glucose and amino acids. The excess of glucose is converted into glycogen which is stored in the liver for later use. When an individual feels deficiency of food, the glycogen is converted into glucose and is transferred to the blood stream via hepatic veins. (ii) Harmful nitrogenous waste like ammonia is converted into urea which is later removed by kidneys. Thus the blood is detoxified (purified) of harmful nitrogenous waste. (iii) Liver produces blood proteins which are put into blood circulation.

Spleen

Spleen is the largest single mass of lymphatic tissue in the body. The spleen is covered by a covering, the **visceral peritoneum**. Next to the visceral peritoneum there is a **capsule** which gives rise to strands called **trabeculae.** Spleen has two types of pulps : the **white pulp** and the **red pulp.** The white pulp consists of small patches of lymphatic nodules containing white blood corpuscles. Each white pulp surrounds an arteriole. The main mass of spleen is formed of red pulp. The red pulp is rich in RBCs. The red pulp also contans **Cords of Billroth** (blood spaces) and **macrophages** (phagocytes). The spleen performs the following functions : (i) Haemopoiesis (formation of blood), (ii) Phagocytosis, (iii) As reservoir of blood —'Blood Bank', (iv) As filtering organ.

DISORDERS OF CIRCULATORY SYSTEM

1. **Hypertension (High blood pressure).** A blood pressure of 120/80 is considered normal. But the increase in blood pressure beyond 140 mm Hg. (systolic) and 90 mm Hg (diastolic) is called high blood pressure (hypertension). The weakened cerebral arteries may finally rupture and a brain haemorrhage follows. Continued high blood pressure may produce a cerebro vascular accident (CVA) or stroke. High blood pressure may damage the blood vessels of the Kidneys. Continued high blood pressure may cause renal failure. In eyes, it may damage the retina, resulting in blurred image.

Generally, a diet full of extremely oily and greasy products, is known to increase cholesterol level, causing thickening of the arteries which result in high blood pressure. Adulterated food is also one of the causes of hypertension. Tobacco smoking speeds up the heart rate, contracts blood vessels and raises blood pressure. Mental tension also causes hypertension. Kidney disorder may be the cause of high BP.

2. **Coronary Artery Disease (CAD).** It is often referred to as **Atherosclerosis** (Gk. *Athero* = gruel, *sclerosis* = hardening) or **Atheroma** (Gk *Athero* = gruel, *oma* = tumour). It refers to the deposition of calcium, fat, cholesterol and fibrous tissue which makes the lumen of arteries narrower.

3. **Arteriosclerosis** (Gk *Arterio* = artery, *sclerosis* = hardening). Hardening and loss of elasticity of the arteries is called **arteriosclerosis.**

4. **Angina.** It is also called **'angina pectoris'**. Heart pain of short duration usually located in the front of the chest. It appears when enough oxygen does not reach the heart muscles. The term **angina pectoris** means chest pain. It can occur both in men and wowen of any age but is more common among the middle aged and elderly people.

5. **Heart failure.** It is the state of heart when it does not pump blood effectively enough to meet

the need of the body. It is sometimes called **congestive heart failure** because congestion of lungs is one of the main symptoms of this disease.

6. **Myocardial infarction (MI).** Death of a part of heart muscle following cessation of blood supply to it. It is **acute heart attack**. The heart mauscle is suddenly damaged by inadequate blood supply.

7. **Coronary thrombosis.** Formation of clot in the coronary artery is called coronary thrombosis. Coronary thrombosis mostly occurs in the *left anterior descending coronary artery.*

8. **Heart Block.** It is a condition in which impulses are interrupted at any point along the conducting system of the heart. Thus impulses do not follow the normal conduction pathway. Two common types of heart block are found. (i) **AV block.** It occurs at the atrioventricular node. The impulses from the SA node do not reach the AV node. (ii) **Bundle branch block.** It involves one of the branches of the bundle of His.

9. **Cerebrovascular Accident (CVA).** Sometimes it is referred to as a **stroke,** which is the sudden interruption of blood flow to a portion of the brain because of block or rupture of a cerebral blood vessel. Thus the brain cells do not get oxygen and glucose. This can cause paralysis, loss of speech, etc.

10. **Rheumatic Heart Disease (RHD).** The patient may have an acute rheumatic fever, joint pains and infection of throat. Rheumatic fever may cause permanent damage of one or more valves (mitral or aortic semilunar valves), pericarditis and myocarditis. Recently, a virus has been suggested as a causative factor. The risk of acute rheumatic fever is greatest where there is bad housing, overcrowding and inadequate conditions of hygiene.

11. **Congenital Heart Diseases.** Defects or diseases of the heart from the birth are known as congenital heart diseases and are due to some error in the developement of the heart, *e.g.*, German measles.

READ AND DIGEST

- Blood flow is lowest in blood capillaries which are the smallest blood vessels.
- **Vasa vasorum** is blood vessel which supplies blood to the blood vessel itself.
- **Fibrillation** is a condition in which the heart muscle is contracting very rapidly but in an uncoordinated fashion. There are atrial and ventricular fibrillation. Ventricular fibrillation is immediately life threating unless it can be stopped by **defibrillation**. A machine called a **defibrillator** is used to do this.
- Largest vein in human body— **Inferior vena cava.**
- Largest Artery— **Aorta.**
- The giraffe's blood pressure may be the highest.
- At birth the number of WBCs is more than the RBCs.
- Capillaries were discovered by **Marcello Malpighi in 1661.**
- An excess of urea and other nitrogenous waste in the blood is called **uremia.**
- **Ischaemia.** Inadequate flow of blood to a part of the heart caused by obstruction to its blood supply.
- **Angiography.** X-ray of the blood vessels after injection of radio-opaque substance.
- **Coronary Angiography.** When the contrast medium dye is injected in coronary arteries (arteries of heart) and pictures are taken, it is known as coronary angiography.
- Clearing a blockade in the coronary artery by balloon surgery is called **coronary angioplasty.**
- In arborisation **heartblock,** the defect lies in the Purkinje's fibres.

- With removal of spleen, the leucocytes count rises.
- Excess calcium ions cause increased heart beats.
- Highest haemoglobin percentage is in neonatal (newly born)— 14.5–24.5 per cent.
- RBCs fail to mature if there is a deficiency of vitamin B_{12} and folic acid.
- Papillary muscles are found in heart of mammals.
- A "**Blue baby**" is the name given to an abnormal human baby who has a hole in the ventricular septum so that more oxygenated and less oxygenated blood mix.
- **Adventitia**. Outermost covering of any organ or structure specifically the outer coat of an artery, the **tunica adventitia.**
- Renal vein carries the least amount of urea. However hepatic vein carries maximum amount of urea.
- **Tachycardia.** It is increase in pulse rate above normal.
- **Bradycardia.** It is decrease in the pulse rate below normal.
- **Starling law of Heart.** According to Starling's law the force of contraction of heart is directly proportional to initial length of muscle fibres. So when the forced contraction is more, cardiac output is more and the systolic pressure rises.
- **Blue Whale** has the largest heart in the whole world.
- **Cardiomegaly.** Heart enlargement.
- **Angiology.** Study of blood vascular and lymphatic systems.
- Fish without haemoglobin – An Antarctic fish, *Chaenocephalus*. It has no RBCs. O_2 seems to be carried by blood plasma.
- **Halls** (1732) measured blood pressure for the first time.
- *Laennec* invented stethoscope.

MULTIPLE CHOICE QUESTIONS

1. Hepatic portal system extends from
   (1) Digestive system to liver
   (2) Kidney to liver
   (3) Liver to heart (4) Liver to kidney
2. Which blood vessel has the largest amount of urea?
   (1) Renal vein (2) Hepatic vein
   (3) Hepatic portal vein
   (4) Dorsal aorta
3. Carotid artery supplies
   (1) deoxygenated blood to kidneys
   (2) deoxygenated blood to liver
   (3) oxygenated blood to limbs
   (4) oxygenated blood to brain
4. Deoxygenated blood from wall of heart is carried by
   (1) coronary sinus
   (2) inferior vena cava
   (3) superior vena cava
   (4) pulmonary artery
5. Which one represents pulmonary circulation?
   (1) Left auricle (oxygenated blood → lungs (deoxygenated blood → Right auricle
   (2) Left auricle (deoxygenated blood → lungs (oxygenated blood → Right auricle
   (3) Left auricle (oxygenated blood → lungs (deoxygenated blood → Left auricle
   (4) Right auricle (deoxygenated blood → lungs (oxygenated blood → Left auricle
6. Erythroblastosis foetalis occurs when a factor from mother passes into foetus through placenta
   (1) Rh antigens (2) Agglutinins
   (3) Rh antibodies (4) ABO antibodies
7. Blood leaving liver and moving to heart will have more concentration of
   (1) Bile (2) Glycogen
   (3) Amino acids (4) urea
8. Blood vessel carrying least CO_2 is
   (1) Pulmonary vein (2) Pulmonary artery
   (3) Vena Cava (4) Hepatic vein
9. Which is not true about chordae tendineae?
   (1) They are stripes of muscles fibres
   (2) They are attached to valves
   (3) They are attached to papillary muscles
   (4) They prevent collapsing of valves into atria
10. Which is not detected usually by ECG?
    (1) Arrhythmia
    (2) Myocardial infarction
    (3) Heart block (4) Valvular defects
11. A correct systemic circulation pathway is
    (1) Right auricle → Left ventricle → Aorta → Tissue → Veins
    (2) Right ventricle → Pulmonary aorta → Tissues → Pulmonary vein → Left auricle
    (3) Left atrium → Left ventricle → Aorta → Arteries → Tissues → Veins → Right atrium
    (4) Left auricle → Left ventricle → Pulmonary aorta → Tissues → Right auricle
12. First sound recorded in sphygmomanometer indicates
    (1) Systolic pressure
    (2) Diastolic pressure
    (3) Lubb (4) Dup.
13. Valves occur in
    (1) Arteries, veins and auricles
    (2) Atria, ventricles and veins
    (3) Arteries, veins and ventricles
    (4) SA node, AV node and veins
14. In order for the blood to flow from right ventricle to left ventricle in mammalian heart, it must flow through
    (1) Right ventricle, pulmonary arteries, lungs, pulmonary veins, left atrium
    (2) Right ventricle, pulmonary veins, lungs, pulmonary arteries, left atrium
    (3) Right ventricle, right atrium, lungs, pulmonary veins, left atrium
    (4) Right ventricle, systemic aorta, lungs, pulmonary veins, left atrium
    (DUMET 2010)
15. Cardiac muscles are found in:
    (1) epicardium (2) myocardium
    (3) endocardium (4) all of these
16. The bulk of the heart wall is
    (1) endocardium (2) pericardium
    (3) epicardium (4) myocardium

17. Though the heart is an involuntary organ, the fibres are different from smooth muscles in possessing
(1) striations (2) tendons
(3) mitochondria (4) sarcoplasm

18. Muscular ridges on the interior surface of the atria are called
(1) trabeculae carneae
(2) endocardium
(3) papillary muscles
(4) musculipectinati

19. Foramen ovale is present only in the heart of embryos leading from the right atrium to
(1) left atrium (2) right ventricle
(3) postcaval vein (4) pulmonary artery

20. In mammals, the opening of postcaval in the right atrium is guarded by
(1) mitral valve (2) bicuspid valve
(3) thebesian valve (4) eustachian valve

21. Tricuspid valve is present between the
(1) two atria
(2) two ventricles
(3) left atrium and ventricle
(4) right atrium and ventricle

22. Which one of the following pairs of terms both words represent one and the same thing?
(1) Plasma - Serum
(2) Atrioventricular node - Pacemaker
(3) Leucocytes - Lymphocytes
(4) Mitral valve - Bicuspid valve

23. Mitral valve in mammals guards the opening between
(1) left atrium and left ventricle
(2) right atrium and left ventricle
(3) left atrium and right ventricle
(4) right atrium and right ventricle

24. The thick muscular projections on the walls of the ventricle are called
(1) columnae carneae
(2) conus arteriosus
(3) chordae tendineae
(4) truncus arteriosus

25. Which of the following organs has papillary muscles?
(1) Wall of heart (2) Lungs
(3) Lingual papilla (4) Mammary glands

26. In the heart of man, the mitral valve is attached to the papillary muscles by
(1) Bundle of His
(2) Purkinje fibres
(3) Columnae carneae
(4) Chordae tendinae

27. Which of the following has the thickest walls?
(1) Left auricle (2) Left ventricle
(3) Right auricle (4) Right ventricle

28. Pulmonary aorta in mammalian embryo communicates with carotico-systemic aorta by a thin vessel called ductus arteriosus which later closes and remains in adult as
(1) carotico-pulmonary aperture
(2) ligamentum arteriosus
(3) fossa ovalis
(4) none of the above

29. Which term does not apply to human heart?
(1) Pacemaker (2) Mitral valve
(3) Neurogenic (4) Four chambered

30. 'Heart of Heart' is
(1) SA node (2) AV node
(3) Bundle of His (4) Purkinje fibres

31. SA node is located in
(1) upper lateral wall of left atrium
(2) lower lateral wall of left atrium
(3) lower lateral wall of right ventricle
(4) upper part of wall of right atrium

32. Impulses originating from sinuatrial node are first transmitted to the
(1) Pacemaker
(2) Bundle of His
(3) Purkinje system
(4) Atrioventricular node

33. What happens when the pacemaker is non-functional?
(1) Only ventricles will contract rhythmically
(2) Only the Atria will contract rhythmically
(3) Atria and ventricles contract simultaneously
(4) The cardiac muscles do not contract in a coordinated manner rhythmically

34. Given these structures of the conduction system of the heart
(1) Bundle of His (2) AV node
(3) Bundle branches
(4) Purkinje fibres
(5) SA node
Choose the arrangement that lists the struc-

tures in an order of an action potential passes through them.

(1) 2, 5, 3, 1, 4
(2) 5, 2, 1, 3, 4
(3) 2, 5, 1, 3, 4
(4) 5, 2, 4, 1, 3

35. The duration of cardiac cycle in a normal man is
(1) 0.8 seconds
(2) 80 seconds
(3) 8 seconds
(4) 72 seconds

36. Identify the correct sequence of events in a cardiac cycle
(1) diastole, atrial systole, ventricular diastole
(2) atrial systole, ventricular systole, joint diastole
(3) atrial systole, ventricular diastole, ventricular systole
(4) ventricular diastole, diastole, ventricular systole, atrial systole

37. During systole of heart
(1) only atria contract
(2) only ventricles contract
(3) atria and ventricles contract separately
(4) atria and ventricles contract simultaneously

38. During ventricular systole
(1) oxygenated blood is pumped into the aorta and deoxygenated blood is pumped into the pulmonary artery
(2) oxygenated blood is pumped into the pulmonary artery and deoxygenated blood is pumped into the aorta
(3) oxygenated blood is pumped into the aorta and deoxygenated blood is pumped into the pulmonary vein
(4) oxygenated blood is pumped into the pulmonary vein and deoxygenated blood is pumped into the pulmonary artery

39. The function of vagus nerve innervating the heart is to
(1) maintain constant heartbeat
(2) accelerate the heartbeat
(3) initiate the heartbeat
(4) reduce the heartbeat

40. Sympathetic stimulation
(1) decreases blood pressure
(2) increases heartbeat
(3) decreases heartbeat
(4) not related to heartbeat

41. Heartbeat is accelerated by
(1) cranial nerves and adrenaline
(2) cranial nerves and acetylcholine
(3) sympathetic nerves and epinephrine
(4) sympathetic nerves and acetylcholine

42. Which of the following hormones has no effect on heartbeat?
(1) Oxytocin
(2) Thyroxine
(3) Adrenaline
(4) Noradrenaline

43. Parasympathetic stimulation of the heart
(1) decreases the heart rate
(2) increases cardiac output
(3) increases the force of ventricular contraction
(4) increases the rate of depolarization of the SA node

44. The secretion of vagus nerve, which reduces the heart rate, is
(1) dopamine
(2) adrenaline
(3) epinephrine
(4) acetylcholine

45. Rate of heartbeat is maximum in
(1) man
(2) whale
(3) elephant
(4) mouse

46. P wave of ECG indicates
1. activation of SA node
2. depolarization of atrial muscles
3. spread of excitation from AV node to Purkinje fibres
4. repolarisation of atria and depolarization of ventricles

Answer codes:
(1) 1 and 2 are correct
(2) 2 and 4 are correct
(3) 1 and 3 are correct
(4) 1,2 and 3 are correct

47. QRS is related to
(1) SA node activation
(2) atrial relaxation
(3) atrial contraction
(4) ventricular contraction

48. In ECG, what does T wave represent?
(1) Diastole of atria
(2) Systole of ventricles
(3) Repolarisation of ventricles
(4) Diastole of atria and ventricles

49. Which correctly pairs an ECG phase with the cardiac event responsible?
(1) P wave - Depolarization of the ventricles

(2) P wave - Depolarization of the AV node
(3) QRS wave - Depolarization of the ventricles
(4) T wave - Repolarization of the atria

50. Typical 'lubb-dupp' sounds heard during heartbeat are due to
(1) closing of semilunar valves
(2) blood under pressure through aorta
(3) closing of bicuspid and tricuspid valves
(4) closure of bicuspid-tricuspid valves followed by semilunar valves

51. Closure of which of the following makes louder sound of heartbeat?
(1) Thebesian
(2) Eustachian
(3) Semilunar valves
(4) Atrio ventricular valves

52. The "lubb" sound (first heart sound) is caused by the
(1) filling of the ventricles
(2) ventricular contraction
(3) closing of the AV valves
(4) closing of semilunar valves

53. A heart murmur indicates a defective
(1) heart valve (2) bundle of His
(3) sinoatrial node
(4) atrioventricular node

54. Cardiac output is defined as
(1) heart rate times stroke volume
(2) peripheral resistance times heart rate
(3) blood pressure minus peripheral resistance
(4) blood pressure times peripheral resistance

55. Average cardiac output is
(1) 4 L/min (2) 5 L/min
(3) 6.3 L/min (4) 7.3 L/min

56. Which one of the following will be the cardiac output (in litres per minute) of a heart that has a stroke volume of 0.07 litres per minute and is beating at a rate of 90 per minute?
(1) 63.30 (2) 63.00
(3) 00.63 (4) 06.30

57. By which instrument BP of man is determined?
(1) BP meter (2) Ultrasound
(3) Stethoscope
(4) Sphygmomanometer

58. Systolic pressure of heart is higher than diastolic pressure because
(1) arteries contract during systole only
(2) arteries offer resistance to the flowing of blood
(3) volume of blood in heart is greater during systole
(4) blood is forcefully pumped into arteries by the heart during systole

59. The pulse pressure is a measure of the
(1) number of heartbeats per minute
(2) sum of the diastolic & systolic pressure
(3) difference between the arterial and venous pressure
(4) difference between the systolic and diastolic pressure

60. Pressure in the aorta is at its lowest
(1) just before AV valves open
(2) at the time of first heart sound
(3) at the time of second heart sound
(4) just before the semilunar valves open

61. Tachycardia is
(1) abnormal heart rhythm
(2) high blood pressure
(3) slow rate of heartbeat
(4) rapid rate of heartbeat

62. Slowing of heartbeat is called
(1) tachycardia (2) bradycardia
(3) cardiac arrest (4) angina pectoris

63. How many times a red blood corpuscle will have to pass through the heart in its journey from hepatic artery to the aorta?
(1) only once (2) two times
(3) four times (4) several times

64. Pulmonary artery differs from pulmonary vein in having
(1) no endothelium
(2) having strong valves
(3) having oxygenated blood
(4) having thick muscular walls

65. Given these blood vessels
1. Aorta
2. Inferior vena cava
3. Pulmonary arteries
4. Pulmonary veins

Which vessels carry oxygen-rich blood?
(1) 1, 3 (2) 1, 4
(3) 2, 3 (4) 2, 4

66. Which one of the following has elastic wall?
(1) Precaval (2) Postcaval
(3) Dorsal aorta (4) Pulmonary vein

67. Which of the statements is false?
(1) Tunica media is thin in veins
(2) Capillaries have a greater total surface area than any other type of vessel
(3) Exchange between blood and tissue fluid occur across the walls of venules
(4) Small arteries and arterioles present great resistance to blood flow

68. Both pulmonary and renal arteries
(1) have internal valves
(2) contain oxygenated blood
(3) have thick-wall and narrow lumen
(4) deliver carbon dioxide to the organs they supply

69. Blood of which vessel in mammals carries least percentage of urea?
(1) Renal vein (2) Dorsal aorta
(3) Renal artery
(4) Posterior vena cava

70. Maximum surface area of circulating system is seen in
(1) veins (2) heart
(3) arterioles (4) capillaries

71. Which of the following consists of a layer of single cell thickness?
(1) artery (2) venule
(3) capillary (4) arteriole

72. Which of the following is not characteristic of the body's capillaries?
(1) Thin-walls (2) Highly branched
(3) High blood velocity
(4) Large total surface area

73. In a portal system
(1) a vein starts from an organ and ends up in the heart
(2) an artery breaks up in an organ and restarts by union of capillary
(3) a vein enters into an organ other than the heart and breaks up into capillaries
(4) the blood from gut is brought into kidneys before it is poured into posterior vena cava

74. Lymph
(1) transports CO_2 to lungs
(2) transports oxygen to brain
(3) returns interstitial fluid to blood
(4) returns RBCs and WBCs to lymph nodes

75. Which of the following is the largest lymphatic vessel of the human body?
(1) Lacteal duct (2) Thoracic duct
(3) Cisterna chyle
(4) Right lymphatic duct

76. Which of the following is first to receive lymphatic vessels from legs?
(1) Left subclavian vein
(2) Right subclavian vein
(3) Right lymphatic duct
(4) Thoracic duct

77. Which of the following organs can be called a sort of "blood bank"?
(1) Lungs (2) Heart
(3) Liver (4) Spleen

78. Role of spleen of mammals is to
(1) act as a haemopoietic tissue
(2) secrete digestive enzymes
(3) assist kidneys
(4) produce angiotensinogen

79. The thickening and loss of elasticity of arterial walls are called
(1) arthritis (2) aneurysm
(3) arteriosclerosis (4) both (2) and (3)

80. An ischemic injury to the heart that destroys myocardial cells is
(1) heart block
(2) fibrillation
(3) cardiac arrest
(4) myocardial infarction

81. To which of the following, bundle of His passes stimulus for contraction?
(1) Atrium (2) AV node
(3) SA node (4) Purkinje fibre

82. Largest single mass of lymphatic tissue in the body is
(1) lung (2) liver
(3) kidney (4) spleen

83. .... accelerates heartbeat due to stimulation of adrenal medulla by sympathetic nerves
(1) Adrenaline (2) Acetylcholine
(3) Vasopressin (4) Collip's hormone
(Odisha JEE 2010)

84. Which of the following is not a major organ of lymphatic system?

(1) Spleen (2) Kidney
(3) Thymus (4) Lymph nodes

85. Congestion of the lungs is one of the main symptoms in
(1) angina (2) hypotension
(3) heart failure (4) atherosclerosis

86. Consider the following statements
A marathon runner is likely to show
1. Reduced heart rate
2. Enlarged heart
3. Larger stroke volume
4. Decreased arterial blood pressure

Which of the above statement is/are correct?
(1) All of the above (2) 1, 2 and 3
(3) 1 and 2 (4) 1 alone

87. Go through the following statements
(i) Vagus nerve decreases the rate of impulse formation from the SA node and its conduction.
(ii) As the human heart is myogenic in nature, the rate of formation and conduction of cardiac impulse cannot be changed by the action of nerves.
(iii) The end of T-wave in ECG marks the end of systole.
(iv) If the P-wave in ECG is inverted, it indicates that SA node fails to initiate impulse and the atrial muscle depolarises by the impulse originating in A.V. node.

Which of these are correct?
(1) (i), (ii) & (iii) (2) (i), (iii) & (iv)
(3) (ii), (iii) & (iv) (4) All are correct

88. SA node acts as a pacemaker of the heart because of the fact that it
(1) is capable of generating impulses spontaneously
(2) has rich sympathetic innervation
(3) has poor cholinergic innervation
(4) generates impulses at the highest rate

89. Go through the following statements
(i) The stroke volume multiplied by heart rate gives the cardiac output.
(ii) The second heart sound is associated with the closure of semilunar valves
(iii) Heart failure is the same as cardiac arrest or a heart attack.

Which of these are correct?
(1) (i) & (ii) (2) (ii) & (iii)
(3) (i) & (iii) (4) All are correct

90. Go through the following statements
(i) As smaller animals have the higher metabolic rate, their heart rate is higher than that of the larger animals.
(ii) Systoles of artria and ventricles never overlap while their diastoles always partly overlap.
(iii) Cardiac cycle time is inversely proportional to the heart rate

Which of these are correct?
(1) (i) & (ii) (2) (ii) & (iii)
(3) (i) & (iii) (4) All are correct

91. A baby is born with a congenital cardiac defect that allows right atrial blood to bypass the lungs and enter the left atrium. Which of the following structural defects must be surgically repaired to save this baby's life?
(1) Ductus venosus
(2) Foramen ovale
(3) Ductus arteriosus
(4) Ductus vena cavas

*92. Which of the following is false about ECG
(1) P. wave → Atrial depolarization
(2) QRS complex → Ventricular depolarization
(3) T-wave → Ventricular repolarization
(4) ST depression indicates infarction

*93. Find out the wrong statement:
(1) SA node is called the pacemaker of the heart
(2) Tricuspid valve is located between right atrium and right ventricle
(3) By counting the number of QRS complexes that occur in a given time period, one can determine the heart beat rate of an individual
(4) The P-wave represents the depolarization of the atria while QRS complex represents the repolarisation of the ventricles

94. The sequence of flow of blood in the hepatic portal system of a mammal is
(1) caudal vein, hepatic vein, liver, posterior venacava

*92. ST depression indicates ischaemia.
*93. QRS complex represents the depolarization of the ventricles.

(2) intestine, liver, hepatic vein, posterior venacava
(3) kidney, liver, intestine, sinus venosus
(4) posterior venacava, intestine, liver, hepatic vein, portal vein

95. Which one of the following is a matching pair?
(1) Lubb – Sharp closure of AV valves at the beginning of ventricular systole
(2) Dup – Sudden opening of semilunar valves at the beginning of ventricular diastole
(3) Pulsation of the radial artery – valves in the blood vessels
(4) Initiation of the heart beat – Purkinje fibres

96. If there is a blockage between the AV node and AV bundle, how will this affect the appearance of the ECG?
(1) P – R interval would be smaller
(2) There would be more P waves than QRS complexes
(3) There would be more QRS complexes than P waves
(4) None of the above

97. Pulmonary aorta in mammalian embryo communicates with aorta by a thin vessel called ductus arteriosus which later closes and remains in adult as
(1) Fossa ovalis
(2) Ligamentum arteriosus
(3) Carotico-pulmonary aperture
(4) None of the above

98. All of the following are true except
(1) Trabeculae carnae, the muscular ridges of ventricles are also known as columnae carnae
(2) Musculi pectinati are present in ventricular walls
(3) There are three papillary muscles in right ventricle and two in left ventricle
(4) Papillary muscles are attached to AV valves through chordae tendinae

99. If all chordae tendinae are weakened or severed, the immediate effect would be
(1) fall in diastolic pressure and unaffected systolic pressure
(2) diastolic pressure unaffected but fall in systolic pressure
(3) fall in both diastolic and systolic pressure
(4) both diastolic and systolic pressure unaffected

100. Narrowing of which of the following heart valves would cause blood to accumulate in the left atrium?
(1) Tricuspid valve (2) Aortic valve
(3) Mitral valve (4) Pulmonic valve

***101.** Go through the following statements
(i) The inner surface of atria have got transverse muscular ridges called papillary muscles.
(ii) Chordae tendinae are special fibrous cords attached to the AV valves and prevent them from collapsing back into the atria during powerful ventricular contraction.
(iii) The neurogenic heart stops functioning immediately after removal from the body.
(iv) The conduction of cardiac impulse is slowest in the A.V. node

Which of these are correct?
(1) (i), (ii)& (iii) (2) (ii), (iii) & (iv)
(3) (i) & (iii) (4) (ii) & (iv)

***102.** Read the following statements
(i) The cardioinhibitory centre of medulla oblongata is connected with the heart through vagus nerve.
(ii) Carotid sinus is the chemoreceptor located in the wall of external carotid artery.
(iii) The signals from carotid sinus are transmitted through Hering's nerve to the glossophyrangeal nerve and then to the medulla oblongata.
(iv) Adrenaline has a greater effect on heart activity than noradrenaline.

Which of these are correct?
(1) (i), (ii) & (iii) (2) (i), (iii) & (iv)
(3) (i) & (iii) (4) All are correct

103. Go through the following statements
(i) Hypophysial portal vein carries blood from the hypothalamus to the anterior lobe of the pituitary gland.

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*101. Papillary muscles are present in the ventricles. Atria have got musculipectinati.
*102. Carotid sinus is the baroreceptor located in the wall of internal carotid artery.

(ii) The central nervous system lacks lymphatic channels.

(iii) The thoracic duct drains into the left subclavian vein.

(iv) Hepatic portal vein is formed by the union of superior mesenteric vein and splenic vein.

Which of these are correct?

(1) (i), (ii) & (iii)
(2) (ii), (iii) & (iv)
(3) (i), (iii) & (iv)
(4) All are correct

*104. Read the following statements

(i) The nodal musculature of the heart has the ability to generate action potentials without any external stimuli.

(ii) The AV node is located in the right ventricle close to the AV septum

(iii) The stroke volume is the amount of blood pumped out by each ventricle per minute.

Which of these are correct?

(1) (i) & (ii)
(2) (ii) & (iii)
(3) Only (ii)
(4) Only (i)

105. ECG depicts the depolarisation and repolarisation processes during the cardiac cycle. In the ECG of a normal healthy individual one of the following waves is not represented.

(1) Depolarisation of atria
(2) Repolarisation of atria
(3) Depolarisation of ventricles
(4) Repolarisation of ventricles

106. Which of the following statements is incorrect?

(1) A person of 'O' blood group has anti 'A' and anti 'B' antibodies in his blood plasma.
(2) A person of 'B' blood group cannot donate blood to a person of 'A' blood group.
(3) Blood group is designated on the basis of the presence of antibodies in the blood plasma.
(4) A person of AB blood group is universal recipient.

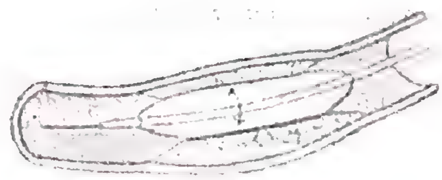
107. In which one of the following pairs the two items mean one and the same thing?

(1) Malleus - Anvil
(2) SA node - Pace maker
(3) Leucocytes - Lymphocytes
(4) Haemophilia - Blood cancer

108. An artificial pace maker is implanted subcutaneously and connected to the heart in patients

(1) having 90% blockage of the three main coronary arteries
(2) having a very high blood pressure
(3) with irregularity in the heart rhythm
(4) suffering from arteriosclerosis

109. The figure below shows an angiogram of the coronary blood vessel. Which one of the following statements correctly describes, what is being done?



(1) It is coronary artery which has a cancerous growth that is being removed.
(2) It is coronary artery which is blocked by a plaque and the same is being cracked.
(3) It is coronary vein in which the defective valves are being opened.
(4) It is coronary vein blocked by a parasite (blood fluke) that is being removed.

110. The chief difference between the erythrocytes of man and frog is

(1) Human erythrocytes have more haemoglobin
(2) Human erythrocytes have more nuclei
(3) Human erythrocytes have no nuclei
(4) Human erythrocytes have less haemoglobin

111. Formation of blood corpuscles is known as

(1) Haemolysis
(2) Rouleaux
(3) Haemopoiesis
(4) Phagocytosis

112. ESR (erythrocyte sedimentation rate) is meant for knowing

(1) degree of disease
(2) erythrocyte count
(3) study of plasma
(4) calculation of haemoglobin

113. The cation (mineral) necessary for coagulation of blood is

(1) Na (2) Ca (3) K (4) Cl

114. Removal of calcium from freshly collected blood would

*104. AV node is located in the right atrium. Stroke volume is amount of blood pumped in one beat.

(1) accelerate clotting
(2) prevent clotting
(3) cause immediate clotting
(4) prevent destruction of haemoglobin

115. RBC placed in distilled water will
(1) burst (2) shrink
(3) stick to one another
(4) divide

116. Largest corpuscles of mammalian blood are
(1) Lymphocytes (2) Basophils
(3) Erythrocytes (4) Monocytes

117. The ratio of RBC to WBC in humans is
(1) 6 : 1 (2) 60 : 1
(3) 600 : 1 (4) 6000 : 1

118. Cells formed in bone marrow include
(1) RBC
(2) RBC, leucocytes and platelets
(3) Leucocytes
(4) Lymphocytes

119. Thrombocytes have a life of
(1) 3 – 4 weeks (2) 4 – 5 weeks
(3) 4 – 5 days (4) 4 – 5 hours

120. Donor X and recipient Y belong to same blood group. Transfusion has led to RBC agglutination because
(1) X is Rh^+, Y is Rh^-
(2) X is Rh^-, Y is Rh^+
(3) Both are Rh^+
(4) Both are Rh^-

121. Which is correct about leucocytes?
(1) They are red coloured
(2) They can cross capillaries
(3) They are enucleate
(4) Decrease in their number causes leukemia

122. For safe blood transfusion
(1) Donor's RBC should not contain antibodies against recipient's serum
(2) Recipient's serum should not contain antigens against donor's antibodies
(3) Recipient's serum should not contain antibodies against RBC of donors
(4) Recipient's RBC should not contain antibodies against donor's antigens

123. Statements (1) Plasma constitutes 45% of blood. (2) Albumin is plasma protein involved in osmotic balance. (3) Blood clotting factors are present in blood. (4) Plasma without clotting factors is serum. (5) Minerals are not found in blood.
(1) 1 – 4 correct, 5 wrong
(2) 1 – 2 correct, 3, 4, 5 wrong
(3) 2, 3, 4 correct, 1 and 5 wrong
(4) 1 and 5 correct, 2, 3, 4 wrong

124. Platelets are given in case of
(1) Anaemia (2) Polycythemia
(3) Thrombocytopenia (4) Leucopinea

125. Which blood transfusion is correct?
(1) $A \rightarrow B$ (2) $B \rightarrow A$
(3) $AB \rightarrow A$ (4) $O \rightarrow B$

126. Go through the following table

A. Basophils	(i) Megakaryocyte
B. Monocytes	(ii) Allergy
C. Thrombocytes	(iii) Macrophages
D. B- Lymphocytes	(iv) Serotonin
E. Eosinophils	(v) Plasma cells

Choose the option which matches the components on the left with the related components on the right
(1) A – (iii); B – (v); C – (iv); D – (ii); E – (i)
(2) A – (v); B – (iii) C – (i); D – (iv) E – (ii)
(3) A – (ii); B – (iv); C – (v); D – (iii); E – (i)
(4) A – (iv); B – (iii); C – (i); D – (v); E – (ii)

127. Which statement is incorrect regarding human blood?
(1) Average leucocyte count is 6000- 8000 mm^{-3}
(2) Average RBC count is 2-4 million mm^{-3}
(3) Proteins contribute about 8 percent of plasma
(4) A healthy human has about 12-16 gms of haemoglobin per 100 ml blood

128. Which of the following is present in both plasma and serum in humans.
(1) WBCs (2) Fibrinogen
(3) RBCs (4) Albumin

129. Cells of human blood can be arranged in a series of increasing number per cubic millimeter of blood as follows
(1) Erythrocytes < Lymphocytes < Platelets < Basophils < Neutrophils
(2) Basophils < Lymphocytes < Neutrophils < Platelets < Erythrocytes
(3) Lymphocytes < Basophils < Platelets < Neutrophils < Erythrocytes

(4) Neutrophils < Basophils < Lymphocytes < Platelets < Erythrocytes

130. Which of the following substances, if introduced into the blood stream, would cause coagulation of blood at the site of its introduction?
(1) Thromboplastin
(2) Fibrinogen
(3) Heparin
(4) Prothrombin

131. A drop of each of the following is placed separately on four slides. Which of them will not coagulate?
(1) Blood serum
(2) Sample from the thoracic duct of lymphatic system
(3) Whole blood from pulmonary vein
(4) Blood plasma

132. Which one of the following mammalian cells is *not* capable of metabolizing glucose to carbon-dioxide aerobically?
(1) Unstriated muscle cells
(2) Liver cells
(3) Red blood cells
(4) White blood cells

*133. Compared to blood our lymph has
(1) More WBCs and no RBCs
(2) More RBCs and less WBCs
(3) No plasma
(4) Plasma without proteins

134. In ECG what is represented by P-wave, QRS complex and T-wave respectively?
(1) Repolarisation of atria; Depolarisation of ventricles; Repolarisation of ventricles
(2) Depolarisation of ventricles; Depolarisation of atria; Repolarisation of ventricles
(3) Repolarisation of ventricles; Depolarisation of atria; Depolarisation of ventricles
(4) Depolarisation of atria; Depolarisation of ventricles; Repolarisation of ventricles *(AIIMS – 2010)*

135. In humans, blood passes from the post caval to the diastolic right atrium of heart due to
(1) pressure difference between the post caval and atrium
(2) pushing open of the venous valves
(3) suction pull
(4) stimulation of the sino auricular node

136. In a standard ECG which one of the following alphabets is the *correct* representation of the respective activity of the human heart?
(1) T – end of diastole
(2) P – depolarization of the atria
(3) R – repolarisation of ventricles
(4) S- start of systole

137. What is true about RBCs in humans?
(1) They do not carry CO_2 at all
(2) They carry about 20 – 25 per cent of CO_2
(3) They transport 99.5 per cent of O_2
(4) They transport about 80 per cent oxygen only and the rest 20 per cent of it is transported in dissolved state in blood plasma *(CBSE PRELIMS – 2010)*

138. If due to some injury the chordae tendinae of the tricuspid valve of the human heart is partially non-functional, what will be the immediate effect?
(1) The flow of blood into the pulmonary artery will be reduced
(2) The flow of blood into the aorta will be slowed down
(3) The 'pacemaker' will stop working
(4) The blood will tend to flow back into the left atrium
(CBSE PRELIMS – 2010)

139. Fastest distribution of some injectible material/medicine and with no risk of any kind can be achieved by injecting it into the
(1) muscles (2) arteries
(3) veins (4) lymph vessels
(CBSE MAINS – 2010)

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*133. None of the choices seem to be correct. Lymph has WBC count lesser than that of blood. Lymph contains proteins. But if one answer needs to be chosen, then (a) is the correct answer.
*136. P → Depolarization of atria (contraction of atria) ; Q → Marks beginning of systole.
R → Ventricular depolarization ;
T → Ventricular repolarisation (ventricular relaxation) ; End of T wave marks the end of the systole.
- QRS are the depolarization waves of ventricles.

140. The haemoglobin content per 100 ml of blood of a normal healthy human adult is
(1) 5 – 11 g (2) 25 – 30 g
(3) 17 – 20 g (4) 12 – 16 g
(CBSE MAINS – 2010)

141. Given below are four statements (i) – (iv) regarding human blood circulatory system
(i) Arteries are thick-walled and have narrow lumen as compared to veins
(ii) Angina is acute chest pain when the blood circulation to the brain is reduced
(iii) Persons with blood group AB can donate blood to any person with any blood group under ABO system
(iv) Calcium ions play a very important role in blood clotting
Which two of the above statements are correct?
(1) (i) & (iv) (2) (i) & (ii)
(3) (ii) & (iii) (4) (iii) & (iv)
(CBSE MAINS – 2010)

142. A portion of the cardiovascular system that transports oxygen-depleted blood from the heart to the lungs, and brings oxygenated blood back to the heart is referred as
(1) Coronary circulation
(2) Systemic circulation
(3) Pulmonary circulation
(4) Single circulatory system
(CHD CET – 2010)

143. Which blood group lacks antigen on their RBCs?
(1) O (2) A (3) B (4) AB
(H P. PMT– 2010)

144. Second heart sound is associated with the
(1) lub – closure of the Semilunar valves
(2) lub – closure of the Tricuspid and Bicuspid valves
(3) dub – closure of the Tricuspid and Bicuspid valves
(4) dub – closure of the Semilunar valves
(H.P. PMT – 2010)

145. Which of the following prevents the conversion of prothrombin in an undamaged blood vessel ?
(1) Heparin (2) Thrompoplastin
(3) Calcium (4) Fibrinogen
(WB JEE 2010)

146. Which is the correct sequence of arrangement of types of WBC in decreasing order in term of number per mm^3 of human blood ?
(1) Eosinophils > basophils > neutrophils
(2) Neutrophils > eosinophils > basophils
(3) Basophils > eosinophils > Neutrophils
(4) Eosinophils > Neutrophils > basophils
(WB JEE 2010)

147. Red cell count is carried out by
(1) haemocytometer
(2) haemoglobinometer
(3) sphygmomanometer
(4) electrocardiogram (Odisha JEE 2010)

148. Rh factor can produce disease
(1) AIDS
(2) Turner's syndrome
(3) erythroblastosis foetalis
(4) sickle-cell anaemia
(Odisha JEE 2010)

*149. Find out the wrong statement.
(1) SA node is called the pacemaker of the heart
(2) Tricuspid valve is located between right atrium and right ventricle
(3) By counting the number of QRS complexes that occur in a given time period, one can determine the heart beat rate of an individual
(4) The P-wave represents the depolarization of the atria while QRS complex represents the repolarisation of the ventricles
(AIIMS – 2011)

150. 'Bundle of His' is a part of which one of the following organs in humans?
(1) Brain (2) Heart
(3) Kidney (4) Pancreas
(CBSE PRELIMS – 2011)

151. Arteries are best defined as the vessels which
(1) supply oxygenated blood to the different organs
(2) carry blood away from the heart to different organs
(3) break up into capillaries which reunite to form a vein
(4) carry blood from one visceral organ to another visceral organ
(CBSE PRELIMS – 2011)

*149. QRS complex represents the depolarization of the ventricles.

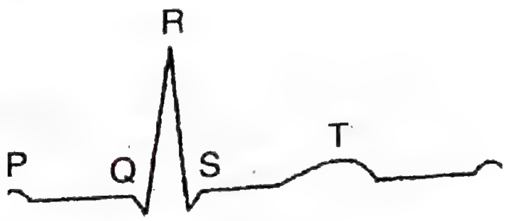
152. Which one of the following statements is correct regarding blood pressure?
(1) 130/90 mmHg is considered high and requires treatment
(2) 100/55 mmHg is considered an ideal blood pressure
(3) 105/50 mmHg makes one very active
(4) 190/110 mmHg may harm vital organs like brain and kidney
(CBSE PRELIMS – 2011)

153. A person with unknown blood group under ABO system, has suffered much blood loss in an accident and needs immediate blood transfusion. His one friend who has a valid certificate of his own blood type, offers for blood donation without delay. What would have been the type of blood group of the donor friend?
(1) Type B (2) Type AB
(3) Type O (4) Type A
(CBSE PRELIMS – 2011)

154. Which one of the following plasma proteins is involved in the coagulation of blood?
(1) An albumin
(2) Serum amylase
(3) A globulin
(4) Fibrinogen
(CBSE PRELIMS – 2011)

155. Bulk of carbon dioxide (CO_2) released from body tissues into the blood is present as
(1) bicarbonate in blood plasma and RBCs
(2) free CO_2 in blood plasma
(3) 70% carbamino-haemoglobin and 30% as bicarbonate
(4) carbomino-haemoglobin in RBCs
(AIPMT (Mains) 2011)

156. Given below is the ECG of a normal human. Which one of its components is correctly interpreted below



(1) Complex QRS – one complete pulse
(2) Peak T – Initiation of total cardiac contraction
(3) Peak P and Peak R together – systolic and diastolic blood pressures
(4) Peak P – Initiation of left atrial contraction only
(CBSE MAINS – 2011)

157. Which is the first Heart sound?
(1) Lub associated with the closure of Semilunar valves
(2) Lub associated with the closure of tricuspid and bicuspid valves
(3) Dub associated with the closure of tricuspid and bicuspid valves
(4) Dub associated with the closure of Semilunar valves
(H. P. PMT – 2011)

158. A certain road accident patient with unknown blood group needs immediate blood transfusion. His one doctor friend at once offers his blood. What was the blood group of the donor?
(1) Blood group AB
(2) Blood group O
(3) Blood group A
(4) Blood group B
(CBSE PRELIMS – 2012)

159. Which one of the following human organs is often called the 'graveyard' of RBCs?
(1) Spleen (2) Liver
(3) Gall bladder (4) Kidney
(CBSE MAINS – 2012)

160. Maximum amount of oxygen is lost from the blood in
(1) Arteries
(2) Capillaries of body
(3) Left atrium of heart
(4) Capillaries surrounding alveoli

161. Haemoglobin breakdown occurs in
(1) Liver (2) Kidney
(3) Lungs (4) Heart

162. Blood diffuses out of the capillaries due to
(1) hydrostatic pressure of Interstitial fluid
(2) osmotic pressure of capillaries
(3) hydrostatic pressure of capillaries
(4) osmotic pressure of interstitial fluid

163. In humans, the right artrioventricular aperture of the heart is guarded by
(1) Monocuspid valve
(2) Bicuspid valve
(3) Tricuspid valve
(4) Tetracuspid valve

164. Which one of the following human cells does not contain mitochondria ?
(1) Nerve cell
(2) Red blood cell
(3) Liver cell
(4) White blood cell
(West Bengal JEE 2011)

165. Which one of the following is the correct pathway for propagation of cardiac impulse ?
(1) SA node → AV node → Bundle of His → Purkinje fibres
(2) AV node → Bindle of His → SA node → Purkinje fibres
(3) SA node → Purkinje fibres → AV node → Bundle of His
(4) Purkinje fibres → AV node → SA node → Bundle of His
(West Bengal JEE 2011)

166. The gene of sickle cell anaemia is inherited by
(1) blood cells
(2) bone cells
(3) sex chromosomes
(4) autosomes
(West Bengal JEE 2011)

167. Foramen ovale
(1) connects the two atria in the foetal heart
(2) is a condition in which the heart valves do not completely close
(3) is a shallow depression in the interventricular septum
(4) is a connection between the pulmonary trunk and the aorta in the foetus
(DUMET – 2011)

168. To obtain a standard ECG, a patient is connected to the machine with three electrodes
(1) One to each wrist and to the left ankle
(2) One to each ankle and to the left wrist
(3) One to each wrist and to the left chest region
(4) One to each ankle and to the left chest region
(DUMET – 2011)

169. Circulatory system does not help in
(1) transport of respiratory gases
(2) transport of hormones
(3) transport of food materials
(4) transfer of impulses
(Odisha JEE 2012)

170. Blood pressure is measured by
(1) barometer
(2) sphygmomanometer
(3) stethoscope
(4) electroencephalogram
(Odisha JEE 2012)

171. Bursa of Fabricius is an important organ of birds. This organ is associated with
(1) generation of basophils
(2) production of uric acid
(3) metabolism of fatty acid
(4) generation of B-cell
(West Bengal JEE 2012)

172. The blood vessel which supplies oxygenated blood to cardiac tissue is
(1) coronary artery (2) coronary vein
(3) coronary sinus (4) pulmonary vein
(West Bengal JEE 2012)

173. In a normal adult human, the average cardiac output is
(1) 47 ml (2) 70 ml
(3) 5 litres (4) 3.3 litres
(West Bengal JEE 2012)

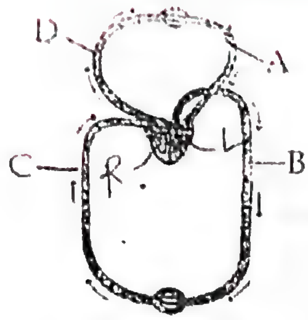
174. 'Lubb' sound produced during heart beat is caused by
(1) ventricular diastole
(2) ventricular systole
(3) atrial diastole
(4) atrial systole *(AMU 2012)*

175. The number of action potentials that can be generated by sino-atrial node is
(1) 42 – 50/min (2) 100 – 120/min
(3) 70 – 75/min (4) 80 – 120/min
(H.P. PMT – 2012)

176. A woman with blood type 'O' has a child with blood type 'O'. If she claims a friend of hers with blood group 'A' as the father of the child, then the genotype of the father would be
(1) I^OI^O (2) I^AI^B
(3) I^AI^O (4) I^BI^O
(H.P. PMT – 2012)

177. If blood pressure reads, 140 systole and 90 diastole the condition is called
(1) Hypertension
(2) Hypotension
(3) Normal (4) Ischemia
(H. P. PMT – 2012)

178. Figure shows schematic plan of blood circulation in humans with labels A to D. Identify the correct label and give its function/s



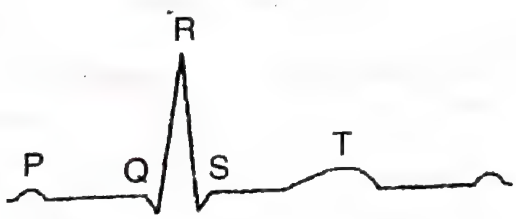
(1) C-Vena Cava-takes blood from body parts to right auricle, PCO_2 = 45 mm Hg
(2) D-Dorsal aorta-takes blood from heart to body parts, PO_2 = 95 mm Hg
(3) A-Pulmonary vein –takes impure blood from body parts, PO_2 = 60 mm Hg
(4) B-Pulmonary artery –takes blood from heart to lungs, PO_2 =90 mm Hg

(NEET – 2013)

179. If two persons with 'AB' blood group marry and have sufficiently large number of children, these children could be classified as 'A' blood group : 'AB' blood group: 'B' blood group in 1:2:1 ratio. Modern technique of protein electrophoresis reveals presence of both 'A' and 'B' type proteins in 'AB' blood group individuals. This is an example of
(1) Partial dominance
(2) Complete dominance
(3) Codominance
(4) Incomplete dominance

(NEET – 2013)

***180.** The diagram given here is the standard ECG of a normal person. The P-wave represents the



(1) Beginning of the systole
(2) End of systole
(3) Contraction of both the atria
(4) Initiation of the ventricular contraction

(HP PMT 2012; NEET – 2013)

In each of the following questions, a statement of ASSERTION [A] is given followed by a corresponding statement of REASON [R] just below it. Of the statements, mark the correct answer as —

(A) If both A and R are true and R is the correct explanation of A
(B) If both A and R are true but R is not the correct explanation of A
(C) If A is true but R is false
(D) If both A and R are false

181. **Assertion:** Smaller the organism higher is the rate of metabolism per gram weight

Reason: The heart rate of a six-month-old baby is much higher than that of an old person.

In case of questions of Assertion-Reason, follow the following instructions
(1) If both Assertion and Reason are true and the Reason is the correct explanation of the Assertion, then mark a.
(2) If both Assertion and Reason are true but the Reason is not the correct explanation of the Assertion, then mark b.
(3) If Assertion is true statement but Reason is false, then mark c.
(4) If both Assertion and Reason are false statements then mark d.

182. **Assertion** : Persons suffering from haemophilia fail to produce blood clotting factor VIII.

Reason : Prothrombin producing platelets in such persons are found in very low concentration.
(1) If both Assertion and Reason are true and the Reason is the correct explanation of the Assertion, then mark a.
(2) If both Assertion and Reason are true but the Reason is not the correct explanation of the Assertion, then mark b.
(3) If Assertion is true statement but Reason is false, then mark c.
(4) If both Assertion and Reason are false statements, then mark d.

***180.** Both the options (1) and (3), are correct.
P wave represents atrial depolarisation, *i.e.*, atrial systole (contraction of atria). Cardiac cycle consists of first systole of heart followed by diastole. Cardiac systole consists of first atrial systole, followed by ventricular systole. Thus beginning of systole of heart is represented by atrial systole which is further respresented by the P wave.

183. How do parasympathetic neural signals affect the working of the heart?
(1) Heart rate decreases but cardiac output increases
(2) Reduce both heart rate and cardiac output
(3) Heart rate is increased without affecting the cardiac output
(4) Both heart rate and cardiac output increase

(AIPMT 2014)

184. Person with blood group AB is considered as universal recipient because he has
(1) Both A and B antigens in the plasma but no antibodies.
(2) Both A and B antigens on RBC but no antibodies in the plasma
(3) Both A and B antibodies in the plasma
(4) No antigen on RBC and no antibody in the plasma

(AIPMT 2014)

185. A man with blood group "A" marries a woman with blood group "B". What are all the possible blood groups of their offsprings?
(1) A, B and AB only
(2) A, B, AB and O
(3) O only
(4) A and B only

(AIPMT 2015)

186. Which one of the following is **correct?**
(1) Serum = Blood + Fibrinogen
(2) Lymph = Plasma + RBC + WBC
(3) Blood = Plasma + RBC + WBC + Platelets
(4) Plasma = Blood – Lymphocytes

(AIPMT 2015)

187. Blood pressure in the mammalian aorta is maximum during
(1) diastole of the right ventricle
(2) systole of the left ventricle
(3) diastole of the right atrium
(4) systole of the left atrium

(AIPMT 2015)

188. Erythropoiesis starts in
(1) Liver
(2) Spleen
(3) Red bone marrow
(4) Kidney

(AIPMT 2015)

189. Which one of the following animals has two separate circulatory pathways?
(1) Frog
(2) Lizard
(3) Whale
(4) Shark

(AIPMT Retest 2015)

190. If you suspect major deficiency of antibodies in a person, to which of the following would you look for confirmatory evidence?
(1) Fibrinogin in plasma
(2) Serum albumins
(3) Haemocytes
(4) Serum globulins

(AIPMT Retest 2015)

191. Doctors use stethoscope to hear the sounds produced during each cardiac cycle. The second sound is heard when
(1) AV valves open up
(2) Ventricular walls vibrate due to gushing in of blood from atria
(3) Semilunar valves close down after the blood flows into vessels from ventricles
(4) AV node receives signal from SA node

(AIPMT Retest 2015)

192. Blood pressure in the pulmonary artery is
(1) more than that in the carotid
(2) more than that in the pulmonary vein
(3) less than that in the venae cavae
(4) same as that in the aorta

(AIPMT NEET 2016)

193. It is much easier for a small animal to run uphill than for a large animal, because
(1) smaller animals have a higher metabolic rate.
(2) small animals have a lower O_2 requirement.

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*188. As per CBSE website the **Ans is (c).**

(a and b)Erythropoiesis starts earliest in yolk sac which is not given in the options. After that both options (a) Liver and (b) spleen are correct.

(Reference – Text Book of Medical Physiology by Guyton and Hall)

"Production of Red Blood Cells – In the early few weeks of embryonic life, RBCsare produced in the yolk sac. During the middle trimester of gestation, liver is the main organ, although a reasonable number of RBCs are produced in the Spleen and Lymph nodes. Then during the last month or so of gestation and after birth, RBCs are produced exclusively in the Bone marrow."

(3) the efficiency of muscles in large animals is less than in the small animals.
(4) it is easier to carry a small body weight.

(AIPMT/NEET 2016)

***194.** The hepatic portal vein drains blood to liver from

(1) heart (2) stomach
(3) kidneys (4) intestine

(NEET 2017)

195. Frog's heart when taken out of the body continues to beat for sometime.

Select the best option from the following statements.

(i) Frog is a poikilotherm.
(ii) Frog does not have any coronary circulation.
(iii) Heart is 'myogenic' in nature.
(iv) Heart is autoexcitable.

Options

(1) Only (iii) (2) Only (iv)
(3) (i) and (ii) (4) (iii) and (iv)

(NEET 2017)

***194.** The hepatic portal system brings blood from the abdominal part of the alimentary canal (i.e., from lower third of oesophagus to halfway down the anal canal), gall bladder, pancreas and spleen to the liver.
Hence, both options (b) and (d) are the correct answers.

ANSWERS

1. (1)	2. (2)	3. (4)	4. (1)	5. (4)	6. (3)	7. (4)	8. (1)	9. (1)	10. (4)
11. (3)	12. (1)	13. (2)	14. (1)	15. (2)	16. (4)	17. (1)	18. (4)	19. (1)	20. (4)
21. (4)	22. (4)	23. (1)	24. (1)	25. (1)	26. (4)	27. (2)	28. (2)	29. (3)	30. (1)
31. (4)	32. (4)	33. (4)	34. (2)	35. (1)	36. (2)	37. (3)	38. (1)	39. (4)	40. (2)
41. (3)	42. (1)	43. (1)	44. (4)	45. (4)	46. (1)	47. (4)	48. (3)	49. (3)	50. (4)
51. (3)	52. (3)	53. (1)	54. (1)	55. (2)	56. (4)	57. (4)	58. (4)	59. (4)	60. (4)
61. (4)	62. (2)	63. (2)	64. (4)	65. (2)	66. (3)	67. (3)	68. (3)	69. (1)	70. (4)
71. (3)	72. (3)	73. (3)	74. (3)	75. (2)	76. (4)	77. (4)	78. (1)	79. (3)	80. (4)
81. (4)	82. (4)	83. (1)	84. (2)	85. (3)	86. (2)	87. (2)	88. (4)	89. (1)	90. (4)
91. (2)	92. (4)	93. (4)	94. (2)	95. (1)	96. (2)	97. (2)	98. (2)	99. (2)	100. (3)
101. (2)	102. (2)	103. (4)	104. (4)	105. (2)	106. (3)	107. (2)	108. (3)	109. (2)	110. (3)
111. (3)	112. (1)	113. (2)	114. (2)	115. (1)	116. (4)	117. (3)	118. (2)	119. (3)	120. (1)
121. (2)	122. (3)	123. (3)	124. (3)	125. (4)	126. (4)	127. (2)	128. (4)	129. (2)	130. (1)
131. (1)	132. (3)	133. (1)	134. (4)	135. (1)	136. (2)	137. (2)	138. (1)	139. (3)	140. (4)
141. (1)	142. (3)	143. (1)	144. (4)	145. (1)	146. (2)	147. (1)	148. (3)	149. (4)	150. (2)
151. (2)	152. (4)	153. (3)	154. (4)	155. (1)	156. (1)	157. (2)	158. (2)	159. (1)	160. (2)
161. (1)	162. (3)	163. (3)	164. (2)	165. (1)	166. (4)	167. (1)	168. (1)	169. (4)	170. (2)
171. (4)	172. (1)	173. (3)	174. (2)	175. (3)	176. (3)	177. (1)	178. (1)	179. (3)	180. (3)
181. (2)	182. (3)	183. (2)	184. (2)	185. (2)	186. (3)	187. (2)	188. (3)	189. (3)	190. (4)
191. (3)	192. (2)	193. (1)	194. (2, 4)	195. (4)					

Chapter

19 Excretory Products and their Elimination

THEORY–a quick rundown

Keeping the internal environment of the body constant is called **homeostasis**. Homeostasis is necessary for normal life processes. For maintenance of homeostasis, osmoregulation and excretion are important. **Osmoregulation** is a process that regulates the body's salt and water concentration. **Excretion** is the elimination of metabolic waste products from the animal body to regulate the composition of the body fluids and tissues. **Defecation** is the removal of wastes and undigested food, collectively called faeces, through the anus.

EXCRETORY PRODUCTS IN VARIOUS ANIMALS

(A) Waste Products of Protein Metabolism. In these waste products ammonia is the most toxic, followed by urea and uric acid which is least toxic.

(1) Ammonia Examples : Protozoans (*e.g.*, *Amoeba*, *Paramecium*), Sponges (*e.g.*, *Sycon*), Cnidarians (*Hydra)*, Liver fluke, Tapeworm, *Ascaris*, *Nereis*, Earthworm, Leech, Prawn, Pila, Bony fishes, Salamanders, tadpoles of frog and crocodile. Animals which excrete ammonia are called **ammonotelic** and excretion of ammonia is termed as **ammonotelism**.

(2) Urea. Examples, *Ascaris*, Earthworm, cartilaginous fishes (*e.g.*, Sharks and Rays), Frogs, Toads, Turtles, Alligators, Mammals (*e.g.*, Man). Excretion of urea is known as **ureotelism** and the animals which excrete urea are called **ureotelic**.

(3) Uric Acid. Examples : Most insects (*e.g.*, cockroach), most land crustaceans (*e.g.*, *Oniscus*— Wood louse), land snails (*e.g.*, *Helix*), land reptile (*e.g.*, lizards and snakes), birds. Excretion of uric acid is known as **uricotelism** and the animals which excrete uric acid are called **uricotelic**.

Dual Excretion. Earthworm excretes ammonia when sufficient water is available while it excretes urea in drier surroundings. Lung fishes and *Xenophus* (African toad) excrete ammonia in water but they excrete urea when they lie immovable in moist air or mud during summer. Tadpole of frog excretes ammonia but during metamorphosis it excretes urea. Crocodiles excrete ammonia in water but excrete urea on land. Aquatic turtles excrete both urea and ammonia.

(4) Amino acids. Examples : *Unio*, *Limnaea* (both molluscs) and *Asterias* (star fish). These animals are called **aminotelic** and their mode of excretion is known as **aminotelism**.

(5) **Guanine.** Spiders excrete guanine and are said to be **guanotelic** and their mode of excretion is called **guanotelism**.

(6) **Trimethylamine Oxide (TMO).** It is excreted by certain marine teleost fishes, molluscs and crustaceans.

$$\text{Ammonia} \xrightarrow[\text{Methylation}]{} \text{Trimethylamine} \xrightarrow[\text{Oxidation}]{} \text{TMO}$$

(7) **Allantoin.** It is formed from uric acid as a result of an oxidation reaction catalyzed by the enzyme **uricase**. Allantoin is an excretory product of embryos of amniotes (reptiles, birds and mammals). In embryo the excretory matter is stored in allantois (embryoinic membrane).

(8) **Creatine.** It is found abundantly in muscle but not in other tissues.

(9) **Creatinine.** It is anhydride of creatine. It is formed in the body from creatine. In **muscular dystrophy** (a disease) it is eliminated in urine in great amount.

(10) **Bile Pigments.** These are **bilirubin** and **biliverdin** which are breakdown products of haemoglobin and formed in the liver. They are excreted through bile. High level of bilirubin in blood causes **jaundice**.

(11) **Hippuric Acid.** It is formed in other mammals.

(12) **Ornithuric Acid.** It is formed in birds as nitrogenous waste.

(B) **Waste products of Nucleic Acid Metabolism.** In man, **purines** (adenine and guanine) are changed to uric acid for excretion. Pyrimidines (cytosine, thymine and uracil) are changed to **alanine** for excretion.

(C) **Other Excretory Wastes.**

(1) **Bile Salts.** Bile salts are the sodium and potassium salts of bile acids, which are conjugated with glycine or taurine. The conjugated bile acids namely, glycocholic acid and taurocholic acid form bile salts in combination with sodium or potassium salts.

The bile salts absorbed from intestine are transported by hepatic portal vein back to the liver via the enterohepatic circulation. From liver, the bile salts are re-excreted through bile.

(2) **Excretion of Drugs, Hormones and Other Substances.** The liver is well known for its ability to detoxify or excrete into bile many drugs, including **sulfonamides, penicillin, ampicillin** and **erythromycin**. Several hormones secreted by the endocrine glands are either chemically altered or excreted by the liver, including **thyroxine** and essentially all the **steroid hormones** such as **oestrogen, cortisol** and **aldosterone**. One of the major routes for excreting **calcium** from the body is secretion by the liver into the bile, which passes into the gut and lost in the faeces. The liver also excretes heavy metals like lead, arsenic and bismuth.

The other substances excreted in bile are heavy metals such as copper and iron, some toxins, some bacteria like typhoid bacteria, cholesterol, lecithin and alkaline phosphatase.

(3) **Carbon dioxide.** It is mainly expelled out by lungs. Some carbon dioxide is also excreted through sweat and defecation.

(4) **Water.** Excess of water is a waste product and is eliminated in urine, faeces, sweat and expired air.

(5) **Vitamins.** The excess of water soluble vitamins like vitamin B complex and vitamin C is removed from the body in urine.

(6) **Spices.** Onions, garlic and some other spices have volatile components which leave the body through lungs, the rest are removed by the kidneys.

Excretory Membranes / Excretory Cells / Excretory organs and main nitrogenous Wastes of different Animal Groups

Animal Groups	Excretory Membranes / Excretory Cells / Excretory organs	Main Nitrogenous Waste
1. **Protozoa** (*e.g., Amoeba, Paramecium*)	Plasmalemma, Pellicle.	Ammonia
2. **Porifera** (*e.g., Sycon*)	Plasma membrane of each cell	Ammonia
3. **Cnidaria** (*e.g., Hydra*)	Plasma membrane of each cell	Ammonia
4. **Platyhelminthes** (*e.g., Planaria, Fasciola, Taenia*)	**Protonephridia** with **Flame cells**,	Ammonia
5. **Nemathelminthes** (*e.g., Ascaris*)	'H' shaped excretory system of canals, ducts and complicated "giant cell" called **renette cell.**	Ammonia, Urea
6. **Annelida**		
(i) *Nereis*	**Metanephridia** with nephrostomes	Ammonia
(ii) Earthworm	A metanephridia with or without nephrostomes, opens into the gut or outside, **chloragogen cells**	Ammonia, Urea on land
(iii) Leech	Metanephridia with nephrostomes, forming ciliated organs.	Ammonia, some urea.
7. **Arthropoda**		
(a) Cray fish, Prawn	**Antennary glands** (green glands)	Ammonia
(b) Insects	**Malpighian tubules, Nephrocytes**	Uric acid in land forms and ammonia in aquatic forms.
(c) Centipedes and millipedes	Malpighian tubules	More ammonia than uric acid
(d) Scorpions and spiders	Malpighian tubules, **Coxal glands, hepatopancreas** and nephrocytes in scorpions. Malpighian tubules and coxal glands in Spiders.	Guanine, some xanthine and uric acid
(e) *Peripatus*	Metanephridia, coxal glands, **slime glands, anal glands.**	—
(f) *Limulus* (King crab)	Coxal glands	—
8. **Mollusca** (*e.g.,Unio, Pila*)	Kidneys. In *Unio* kidneys are called **organs of Bojanus.** In *Unio* **Keber's organ** is also excretory organ.	Ammonia in aquatic and Uric acid in land forms
9. **Echinodermata** (*e.g.,*Star fish)	No specialized excretory organs. **Dermal branchiae** and **tube feet** perform excretory function.	Ammonia
10. **Hemichordata** (*e.g.,Balanoglossus*)	**Glomerulus**	—
11. **Chordata**		
(i) **Urochordata** (*e.g.,Herdmania*)	**Neural gland**	—
(ii) **Cephalochordata** (*e.g.,Amphioxus*)	**Pharyngeal nephridia, Hatschek's nephridium. Solenocytes** (flame cells) are present in these nephridia.	—
(iii) **Vertebrata** (*e.g.,* Cyclostomes, Fishes, Amphibians, Reptiles, Birds and Mammals)	One pair of kidneys. Lungs, liver, skin and intestine are accessory excretory organs in many vertebrates.	Ammonia, urea, uric acid

HUMAN EXCRETORY SYSTEM

It comprises a pair of kidneys, a pair of ureters, a urinary bladder and a urethra.

1. **Kidneys.** There is a pair of kidneys which are dark-red, bean shaped, each with a notch, (concavity), the **hilus** (=hilum) on its inner side. The kidney is **metanephric.**

The kidney is covered by a layer of fibrous connective tissue, **the renal capsule,** which protects it from infection and injuries. Around the capsule there is a layer of fat, the **adipose capsule,** and another outer fibrous membrane, the **renal fascia**. Both the fat and the fascia help to protect the kidney. Inner to the capsule there is an outer dark region, the **cortex**, and inner lighter region, the **medulla.** The medulla is divided into a number of conical areas, the **medullary pyramids** (15 or 16). Each renal pyramid terminates into a structure, the **renal papilla**. Between the medullary pyramids the substance of the cortex extends into the medulla and forms the **columns of Bertin**. The medullary pyramids are connected with **minor calyces** (7–13). The minor calyces (sing. calyx) lead into **major calyces.** A human kidney possesses two to three major calyces. The latter open into a funnel shaped structure, the **renal pelvis** which in turn leads into the **ureter**. A kidney has about ten lakh structural and functional units called **nephrons** or **uriniferous tubules**.

2. **Ureters.** The ureter of each kidney leaves from the renal pelvis in the hilus region. They open into the urinary bladder. Ureters are composed of transitional epithelium. They carry urine from the kidneys to the urinary bladder.

3. **Urinary bladder.** It is composed of **transitional epithelium**. The muscular layer of the urinary bladder is well developed and is called **detrusor muscle**. In the area where the bladder and urethra join some of the circular smooth muscles are modified to form the **internal sphincter.** Inferior to the internal sphincter is an **external sphincter** made of skeletal muscles which is under voluntary control of the nervous system. Both the sympathetic and parasympathetic nervous systems innervate the urinary bladder. Internally, the urinary bladder has a triangular area, the **trigone,** between the three openings, two openings through which the ureters enter the bladder and one opening through which the urethra leaves the bladder. The urinary bladder stores urine temporarily.

4. **Urethra.** It is a canal like structure which extends from the neck of the bladder and leads to exterior. Its length differs in the male and female. In female, urethra is short (about 4 cm in length) and carries only urine. It opens by **urethral orifice** (urinary aperture) infront of vaginal aperture (genital aperture). In male, urethra is much longer (about 20 cm in length) opens out at the tip of the penis by **urino genital aperture**. Thus the urethra of male carries both urine and semen.

Nephrons

Each human kidney possesses about one million (ten lakhs) structural and functional units, the **nephrons.** Each nephron is made up of two main parts ; **Malpighian body (renal corpuscle)** and **renal tubule**.

1. Malpighian body comprises a cup shaped **Bowman's capsule** and a network of blood capillaries, the **glomerulus.** The glomerular capillaries consist of **podocytes, basement membrane** and **endothelium.** The renal artery after entering the kidney divides and redivides forming various **afferent renal arterioles.** An afferent renal arteriole enters a Bowman's capsule to form glomerulus. The efferent renal arteriole has narrower lumen than the afferent renal arteriole. Thereafter, an **efferent renal arteriole** leaves the glomerulus. The efferent renal arterioles break up into capillaries around the tubules.

2. The capillaries around the loop of Henle are called **vasa recta.** The 'U'-shaped vasa recta help to retain reabsorbed ions and urea in the interstitial fluid of the medulla. Thus, its high osmotic pressure is maintained. The capillaries in turn unite to form renal venules and the latter together form

the renal vein which leaves the kidney from the hilus. Vasa recta is absent or highly reduced in cortical nephrons.

The Bowman's capsule leads into the renal tubule which becomes coiled in the cortex and is called **proximal convoluted tubule** (PCT). Then it goes downwards as **descending limb** of **loop of Henle.** The descending limb narrows in the region of medulla as a thin segment. The latter again turns upwards as **ascending limb** of **loop of Henle** as thin segment. The latter opens into the thick segment of ascending limb of loop of Henle which proceeds towards the cortex to become coiled **distal convoluted tubule** (DCT). The latter joins **collecting duct.** Collecting ducts unite to form still larger ducts called the **ducts of Bellini.** The latter run through the renal pyramids and open into the renal pelvis.

Types of Nephrons. According to the position, nephrons can be divided into two groups.

(i) **Juxtamedullary Nephrons.** Their glomeruli are placed close to the inner margin of the cortex. The loops of Henle of these nephrons are long and are found deep into the medulla. They are associated with vasa recta.

(ii) **Cortical Nephrons.** These nephrons are more common (about 85%). They have their glomeruli in the outer cortex. The loops of Henle of these nephrons are relatively short and extend a short distance into the medulla. They do not have vasa recta.

Juxtaglomerular Apparatus (JGA)

This apparatus consists of (i) **Juxtaglomerular cells** in the wall of the afferent arteriole near where it enters the glomerulus and large cells, (ii) the **macula densa** of the distal convoluted tubule. The Juxtaglomerular cells secrete an enzyme called **renin.**

A third component of JGA, the **laci cells**, is also reported but the function of these cells is unknown.

UREA CYCLE (ORNITHINE CYCLE)

Urea cycle occurs in the **mitochondria** of the liver cells. Liver converts toxic substances into less toxic ones. Urea is synthesized in liver and transported to kidneys for excretion in urine. Urea is produced through urea cycle which was discovered by Hans Krebs and Kurt Henseleit (1932), hence it is known as **Krebs-Henseleit cycle**. The individual reactions, however, were described in more detail later on by Ratner and Cohen.

Urea cycle includes five steps involving five distinct enzymes. The first two enzymes are present in mitochondria while the rest are localized in cytosol (the cytoplasm minus the mitochondria and endoplasmic reticulum).

(i) **Synthesis of Carbamoyl Phosphate.** Carbamoyl phosphate of mitochondria is formed from NH_4 ions and CO_2. This step consumes two ATPs.

(ii) **Formation of Citrulline.** Citrulline is synthesized from carbamoyl phosphate and ornithine.

(iii) **Synthesis of arginosuccinate.** Argino-succinate is formed from citrulline and aspartate. This step requires ATP.

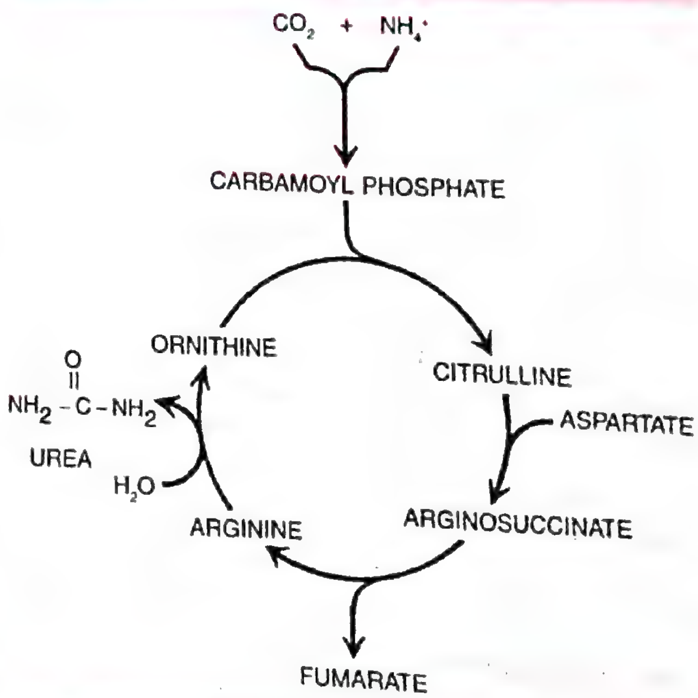


Fig. 19.1. Urea Cycle.

(iv) **Cleavage of arginosuccinate.** Arginosuccinate forms arginine and fumarate.

(v) **Formation of Urea. Arginase** is the fifth and final enzyme that cleaves arginine to form urea and ornithine. This ornithine enters mitochondria for its reuse in the urea cycle. The urea cycle (also called ornithine cycle) is irreversible.

Thus three participating aminoacids are ornithine citrulline and arginine.

Pressure in the Renal Circulation

(i) The pressure is 100 mm Hg in the small arteries and afferent arterioles.

(ii) **Glomerular Hydrostatic Pressure (GHP)** is in the glomerulus which is about 60 mm Hg.

(iii) **Blood Colloidal Osmotic Pressure (BCOP).** This pressure opposes filtration. It is about 32 mm Hg.

(iv) **Capsular Hydrostatic Pressure (CHP).** This pressure also opposes filtration and represents a back pressure of about 18 mm Hg.

(v) **Effective Filtration Pressure (EFP)**

$$\begin{aligned}\text{EFP} &= \text{GHP} - (\text{BCOP} + \text{CHP})\\ &= 60 - (32 + 18)\\ &= 60 - 50 = 10 \text{ mm Hg}\end{aligned}$$

(vi) **Glomerular Filtration Rate (GFR).** It is 125 ml per minute or about 180 litres per day.

(vii) **Filtration Fraction** $= \dfrac{\text{Glomerular Filtration Rate (GFR)}}{\text{Renal Plasma Flow (RPF)}} \times 100$

(Ratio of GFR to RPF)

$$= \frac{125 \text{ ml/min}}{650 \text{ ml/min}} \times 100 = 19.2\%$$

The normal filtration fraction varies from 15 to 20%

URINE FORMATION

Urine formation includes glomerular filtration (ultrafiltration), selective reabsorption and tubular secretion.

1. **Glomerular filtration** (Ultrafiltration). The first step in urine formation is the filtration of blood which is carried out by the glomerulus and therefore, it is called **glomerular filtration.** On an average 1100–1200 ml of blood is filtered by the kidneys per minute which constitutes about 1/5th of the blood pumped out by each ventricle of the heart in a minute. The glomerular capillary blood pressure causes filtration of blood through three layers (i) endothelium of glomerulus (ii) basement membrane of glomerulus and (iii) epithelium of Bowman's capsule. Epithelial cells of Bowman's capsule are called **podocytes**. There are present **slit pores** (minute spaces) in between the podocytes. The blood is filtered through these three membranes. The glomerular capillaries are narrower than that of afferent renal arterioles. Therefore, the blood pressure in the glomerular capillaries becomes very high so that there is continuous process of **ultrafiltration** (filtration under pressure). The filtered out fluid entering into Bowman's capsule is called **glomerular filtrate**. The glomerular filtrate and blood plasma are similar except that glomerular filtrate does not have proteins and fats.

The amount of the filtrate formed by both the kidneys per minute is known as **glomerular filtration rate** (GFR). In the normal person, the glomerular filtration rate is about 125 ml. per minute, (*i.e.*, 180 litres per day).

As stated earlier, there is Juxtaglomerular apparatus (JGA). JGA is formed by cellular modifications **(macula densa)** in the distal convoluted tubule and cellular modification **(Juxta glomerular cells)** in the afferent arteriole at the location of their contact. A fall in GFR can activate the JG cells to release **renin** which can stimulate the glomerular blood flow and thereby the GFR back to normal.

2. **Tubular Reabsorption.** The glomerular filtrate in the Bowman's capsule is almost **isotonic** to blood plasma in composition except for plasma proteins and fats. A comparison of the volume of the filtrate formed per day (180 litres per day) with that of the urine released (1.5 litres), suggest that nearly 99 per cent of the filtrate has to be reabsorbed by the renal tubules. This process is called **reabsorption**. The tubular epithelial cells in different parts of nephron perform this either by active or passive mechanisms. For example, glucose, amino acids, Na^+, etc. in the filtrate are reabsorbed actively whereas the nitrogenous wastes are absorbed by passive transport. Reabsorption of water also occurs passively in the initial segments of the nephron.

3. **Tubular Secretion.** The tubular secretion is opposite of tubular reabsorption. Tubular secretion is also an important step in urine formation as it helps in the maintenance of ionic and acid base balance of body fluids. During urine formation the tubular cells secrete substances like H^+, K^+ and ammonia into the filtrate.

FUNCTION OF THE TUBULES

A. Tubular Reabsorption

1. **Proximal convoluted tubule (PCT).** About 70 to 80% of the filtrate is reabsorbed here. Solutes like glucose, amino acids, vitamins, ketobodies, acetoacetic uric acid, chlorides, sodium, potassium, phosphates etc. of the filtrate are reabsorbed into the blood by diffusion and active transport. Small amounts of ammonia and urea are also reabsorbed. Sulphates and creatinine are not reabsorbed here. Water goes back into the blood by osmosis. The filtrate becomes **isotonic** to blood plasma.

2. **Loop of Henle.** It has descending limb and ascending limb.

1. **Descending limb of loop of Henle.** Sodium and other solutes are not reabsorbed here. The filtrate becomes **hypertonic** to blood plasma.

2. **Ascending limb of loop of Henle.** It is *impermeable to water* but permeable to K^+, Cl^- and Na^+ and partially permeable to urea. Thus in the thick ascending limb of the loop of Henle sodium, potassium, calcium, magnesium, and chloride are reabsorbed. The filtrate becomes **hypotonic** to blood plasma.

3. **Distal convoluted tubule (DCT).** There is active reabsorption of sodium ions from the filtrate under the influence of **aldosterone** (hormone secreted by the cortex of adrenal glands). With associated excretion of potassium and hydrogen ions some Cl ions are also reabsorbed. Water is reabsorbed here under the influence of **antidiuretic hormone** (ADH) or **vaso pressin** secreted by hypothalamus and stored in the posterior lobe of pituitary gland. This makes the filtrate **isotonic** to blood plasma.

4. **Collecting duct.** A considerable amount of water is reabsorbed in the collecting duct under the influence of ADH. Sodium is reabsorbed in the collecting tubule and collecting duct under the influence of aldosterone. The filtrate is now called **urine**. Thus urine is hypertonic to blood plasma.

Some substances such as glucose and amino acids are reabsorbed actively into the blood by the active transport and, therefore, they do not appear in the urine. These substances are called the high **threshold substances**. When their concentration in the blood becomes very high, they are not completely reabsorbed into the blood and start appearing in the urine. The concentration in the blood of a substance such as glucose at the point where it just begins to appear in the urine is called its **renal threshold**. The renal threshold of glucose is about 180 mg per 100 ml blood. When this value is exceeded, glucose begins to appear in the urine.

B. Tubular Secretion.

The tubular secretion is the opposite of tubular reabsorption. It occurs as follows :

1. Creatinine, hippuric acid, pigments, drugs including penicillin are actively secreted into the filtrate in the proximal convoluted tubule from the interstitial fluid. Hydrogen ions and ammonia are also secreted into the proximal convoluted tubule.

2. Urea enters the filtrate by diffusion in the thin segment of the ascending limb of loop of Henle.

3. Potassium, hydrogen ions, ammonia, HCO_3^- ions are secreted by active transport into the filtrate in the distal convoluted tubule.

Tubular secretion probably plays a minor role in the function of human kidneys but in animals like marine fishes desert amphibians, whose nephrons do not possess developed glomeruli, their urine is formed mainly by the tubular secretion of urea, creatinine and mineral ions.

MECHANISM OF CONCENTRATION OF THE FILTRATE

In the birds and mammals including man a **counter current mechanism** is found in the kidney. Due to this mechanism **hypertonic** urine (urine more concentrated than blood) is formed which is essential for conserving body water.

Components of Countercurrent Mechanism. The loop of Henle and Vasa recta (blood capillary loop) play an important role in this mechanism. Interstitial fluid also plays an important role in the counter current mechanism.

The flow of filtrate in the two limbs of loop of Henle is in opposite directions. The flow of blood through the two limbs of vasa recta is also in opposite directions, toward the renal medulla in the descending limb and toward the renal cortex in the ascending limb. Thus there are two **counter current systems** (one in loop of Henle and another in vasa recta) which help in the concentration of the urine.

1. **Loop of Henle.** *Osmolarity of glomerular filtrate is same as that of blood plasma 300 m Osmoil^{-1}. Glomerular filtrate passes through the ascending limb of loop of Henle in the renal medulla. NaCl is absorbed by diffusion in the narrow region and Na^+ and Cl^- ions by active transport in the wide region of ascending limb of loop of Henle. NaCl and Na^+ and Cl^- ions are transported from ascending limb of loop of Henle to the interstitial fluid. Due to the increased concentration of the solutes in the interstitial fluid, water is carried by osmosis from the narrow region of descending limb and the collecting duct as both are permeable to water. The water enters the vasa recta. This converts isotonic glomerular filtrate into a **hypertonic urine** (the osmolarity of urine becomes 4 times, *i.e.*, from 300 m Osmoil^{-1} to about 1200 m Osmoil^{-1} in the inner renal medulla. It means urine is 4 times as concentrated as the human blood plasma.

2. **Vasa Recta.** The walls of the vasa recta are freely permeable to ions, water and urea. As the blood flows in the descending limb of vas rectum (sing. of vasa recta) toward the renal medulla, water is transported from the blood plasma by osmosis into the intersititial fluid increasing the concentration of this fluid. Sodium and chloride ions and urea enter the blood plasma by diffusion. As the blood runs in the ascending limb of vas rectum toward the renal cortex, the reverse takes place. Water re-enters the blood plasma and Na^+ and Cl^- and urea leave due to decrease in interstitial fluid concentration.

Some urea diffuses from the collecting duct into the interstial fluid from which urea enters the ascending limb of loop of Henle. Thus concentration of interstitial fluid is increased. Concentration of the filtrate is also increased which makes the urine more concentrated.

In brief the machanism of concentration of the filtrate can be explained as follows. The proximity (nearness) between the *loop of Henle's* and *vasa recta*, as well as the counter current in them helps

*Osmolarity is soluble concentration expressed as molarity or moles of solute per litre of solution. The unit of measurement for osmolarity is millios mole per litre (mOsmoll^{-1}).

in maintaining an increasing osmolarity towards the inner medullary interstitial fluid, (*i.e.*, from 300 mOsmolL^{-1} in the cortex to about 1200 mOsmolL^{-1} in the inner medulla). This gradient is mainly caused by NaCl and urea. NaCl is transported by the ascending limb of loop of Henle which is exchanged with the descending limb of *vasa recta*. NaCl is returned to the interstitial fluid by the ascending limb of *vasa recta*. Similarly, small amounts of urea enter the narrow portion of the ascending limb of loop of Henle which is transported back to the interstitial fluid by the collecting duct. The above described transport of substances facilitated by the special arrangement of loop of Henle and *vasa recta* is called the **counter current mechanism**. This mechanism helps to maintain a concentration gradient in the medullary interstitial fluid. Presence of such interstitial gradient helps in an easy passage of water from the collecting duct thereby concentrating the filtrate (urine). Human kidneys produce urine about 4 times concentrated than the glomerular filtrate formed.

ADH (= vasopressin). It is secreted by the hypothalamus of the brain and scored in posterior lobe of pituitary gland. It increases reabsorption of water in the distal convoluted tubules and collecting ducts.

Significance of Urea. Besides NaCl, urea is also involved in counter current mechanism. Urea diffuses out of the collecting ducts and enters into the thin ascending limbs. A certain amount of urea is recycled in this way and is trapped in the interstitial fluid.

Effect of Alcohol. Alcohol decreases the level of ADH. This lowers reabsorption of water and increases loss of water in urine. Therefore, beverages having a high content of alcohol cause excessive urination and dehydration.

REGULATION OF KIDNEY FUNCTION

The functions of the kidney are controlled by Antidiuretic hormone (ADH), Juxtaglomerular apparatus (JGA) and Atrial Natriuretic Factor (ANC)

(i) Control by Antidiuretic Hormone (ADH). ADH is secreted by the hypothalamus of the brain and is stored in posterior lobe of the pituitary gland. It increases the reabsorption of water in the distal convoluted tubule and collecting duct.

(ii) Control by Juxtaglomerular Apparatus (JGA). JGA operates a multihormonal **Renin-Angiotensin– Aldosterone System** (RAAS). Juxtaglomerular cells secrete an enzyme, **renin** into the blood stream. Renin changes plasma protein, called **angiotensinogen** to a peptide, called **angiotensin** II, which works as hormone. Angiotensin II increases blood pressure by causing arterioles to constrict. It also increases blood volume in two ways: firstly, it induces the proximal convoluted tubules to reabsorb more NaCl and water and secondly it stimulates the adrenal glands to release a hormone, called **aldosterone** that induces the distal convoluted tubule to absorb more Na^+ and water.

(iii) Atrial Natriuretic Factor (ANF). There is another hormone, a peptide called **Atrial Natriuretic Factor** (ANF) which opposes the regulation by RAAS. The walls of the atria of the heart release ANF in response to an increase in blood volume and pressure. ANF inhibits release of renin from the JGA and thereby inhibits NaCl reabsorption by the collecting duct and reduces aldesterone release from the adrenal gland. Thus ADH, RAAS and ANF regulate the functions of kidneys. As a result they control body fluid osmolarity salt concentration, blood pressure and blood volume.

MICTURITION

The expulsion of urine from the urinary bladder is called **micturition**. It is a reflex process, but in grown up children and adults, it can be controlled voluntarily to some extent.

The urinary bladder and the internal sphincter are supplied by both sympathetic and parasympathetic nervous systems of autonomic nervous system whereas, the external sphincter is supplied by the somatic nerve.

The stimulation of **sympathelic nerve** causes relaxation of detrusor muscle of the urinary bladder and constriction of the internal sphincter. So, it causes filling of the urinary bladder and the sympathetic nerve is called nerve of filling.

The stimulation of **parasympathetic nerve** causes contraction of detrusor muscle and relaxation of the internal sphincter leading to emptying of the urinary bladder. So, the parasympathetic nerve is called the nerve of emptying or nerve of micturition.

Somatic (pudendal) nerve maintains the tonic contraction of the skeletal muscle fibres forming external sphincter so that, the external sphincter is constricted always. During micturition, this nerve is inhibited, thus the somatic (pudendal) nerve is responsible for voluntary control of micturition.

The urine flows out from the urinary bladder through the urethra.

URINE

The colour of urine is caused by the pigment **urochrome**, which is a breakdown product of haemoglobin from worn out red blood corpuscles. The *p*H range of urine is normally between 4.5 and 8.2 depending upon the amount of acidic and basic foods in the diet (average 6.0 pH). Fruits increase the acidity and vegetables increase the alkalinity of the urine. A normal adult person secretes about 1.5 litres of urine in 24 hours. The urine is hypertonic. When the urine is allowed to stand for some time it smells strongly of ammonia due to bacterial degradation of urea to ammonia. The specific gravity of urine is usually between 1.015 and 1.025.

About 95% of the volume of urine is water, other substances are only about 5%. Organic substances include nitrogen, urea, creatine, creatinine, ammonia, uric acid, hippuric acid, oxalic acid, amino acids, allantoin, vitamins, hormones and enzymes. The inorganic substances include chloride, phosphate, sulphate, potassium, sodium, calcium, magnesium, iodine, arsenic and lead. It is important to note that no glucose is normally found in the urine.

Abnormal Urine

Abnormal conditions of urine are the following :

(i) **Albuminuria.** Presence of albumin in urine is called albuminuria. It usually occurs in **nephritis** (inflammation of glomeruli). In this condition the size of the filtering slits enlarges.

(ii) **Glycosuria.** Presence of glucose in urine is known as glycosuria. It occurs in **Diabetes mellitus.**

(iii) **Hematuria.** Presence of blood or blood cells in urine is called hematuria.

(iv) **Ketonuria.** Presence of abnormally high ketone bodies in urine is termed as ketonuria.

(v) **Hemoglobinuria.** Presence of hemoglobin in urine in called hemoglobinuria.

(vi) **Uremia.** Presence of excess urea in urine is known as uremia.

(vii) **Pyuria.** The presence of pus in the Urine is called pyuria.

Deficiency of ADH causes **Diabetes insipidus** which is characterised by excessive dilute urine.

Functions of Kidney

(1) Kidney removes excess of water nitrogenous wastes such as urea and uric acid from the blood, mineral salts such as sodium, potassium in the body, toxic substances, drugs, pigments, excess vitamins from the blood. (2) Kidney controls the fluid balance in the body, therefore, it maintains blood pressure. (3) Kidney secretes an enzyme (which acts as hormone), the **renin** which changes the plasma, protein the **angiotensinogen** (produced by liver) into **angiotensin II.** The latter stimulates the adrenal cortex to secrete **aldosterone** (hormone) which increases the rate of reabsorption of Na^+ in the nephrons. (4) The kidney produces **erythropoietin** (hormone) that stimulates the formation of erythrocytes (RBCs) in the bone marrow.

ARTIFICIAL KIDNEY

Dialysis (Gr. *dia–* through, *lyo–* separate) is carried out by a machine called **artificial kidney**. The artificial kidney is used in acute renal failure. The word dialysis refers to the diffusion of small solute molecules from an area of higher concentration to the area of lower concentration through a semipermeable membrane.

Dialysis is of two kinds— haemodialysis and peritoneal dialysis.

Haemodialysis

When the kidneys are completely damaged and do not function, the patient often receives **haemodialysis** (treatment with an artificial kidney). Haemodialysis is the process of diffusion across a semipermeable membrane to remove unwanted substances from the blood while adding desirable components. The pores in the membrane allow some substances to pass through, however, prevent others. The patient is connected to the machine by a tube attached to an artery often the **radial artery.** Blood from the artery is pumped into a tube that runs through the dialyzer. The dialyzer is filled with **dialysing fluid** which contains the same quantities of electolytes and nutrients as normal plasma but contains no waste products. The **cellophane tube** (a tube bounded by thin membrane) is kept in the dialysing fluid. The membrane of the cellophane tube is impermeable to blood cells and proteins but permeable to urea, uric acid, creatinine and mineral ions. So these wastes diffuse from the blood to the dialysing fluid across the cellophane membrane. Now the blood is returned to the patient's body through a vein usually the **radial vein.** Dialysis is done usually thrice a week in severe uremia. Each time the artificial kidney is used for about 6 hours.

Dr. Belding H. Scribner was inventor of this device that made kidney dialysis possible.

Peritonial Dialysis

The common type of peritonial dialysis is **continuous ambulatory peritonial dialysis** or **CAPD**. In this dialysis an implanted peritonal catheter is used. Fluid is drained into and from the peritoneal cavity by gravity. Exchange occurs between blood of peritoneal membrane and dialysing fluid. CAPD is alternative to haemodialysis and is considerably less expensive.

KIDNEY TRANSPLANTATION

When the kidney failure is not treated with drug and dialysis, a kidney is transplanted from a compatible donor.

The world's first successful organ transplant was kidney transplantation which was undertaken by **David Hume** and **Joreph Kelly** at the Peter Brigham Hospital in Boston in 1954. The first kidney transplant in India was performed on Dec. 1, 1971 at the Christian Medical college, Vellore (Tamil Nadu).

Donor. The donor may be an identical twin or a close relative or any other person. Somtimes kidney of a dead person, who died recently due to accident, is also used.

Success Rate. A kidney transplant from an identical twin, called **Isograft**, is always successful. If kidney is transplanted from other person except twin is called **homograft**, which is also successful with the use of an **immunosuppressant.** The drug, named **cyclosporin** is a good immunosuppressant. It destroys T-cell mediated immune responses, while spares humoral antibody responses.

The success rate of kidney transplantation is variable. Transplanted kidney may function for over 20 years.

Recipient Donor Matching. Recipient and donor are tested for three factors :

(i) **Blood group.** Recipient's blood group should match with donor's blood group.

(ii) **Human Leucocyte Antigen** (HLA). It is located on the surface of the leucocytes (WBCs).

An individual inherits a set of 3 antigens from the father and 3 antigens from the mother. A higher number of matching of these antigens increases the chances of lasting kidney graft for a long time.

(iii) Antibodies. Small amount of blood of recipient and donor are mixed in a tube. If no reaction occurs, the recipient is able to accept the kidney.

ROLE OF OTHER ORGANS IN EXCRETION

Role of Lungs in Excretion. Human lungs regularly remove about 18 L of CO_2 per hour and about 400 ml of water per day in normal resting condition. Water loss through the lungs is small in hot humid climate and large in cold dry climate. Thus CO_2 and water (both are metabolic wastes produced during oxidation of food in the cells) are removed via lungs.

Role of Skin in Excretion. In many aquatic animals ammonia is mainly excreted out into the surrounding water by diffusion through the skin. Human skin has two types of glands: **sudoriferous** (sweat) **glands** and **sebaceous** (oil) **glands.**

(i) Sudoriferous glands (Sweat glands) secrete an aqueous fluid called **sweat.** Sweat contains water (99.5%), NaCl, urea, lactic acid, amino acids and glucose. *Sweat does not contain uric acid.* The volume of sweat varies from negligible to 14L a day, depending upon activity and temperature. When sweat evaporates, it provides cooling to the body. Normal *p*H of sweat is 4.5. Sweat production is also influenced by atmospheric temperature.

(ii) Sebaceous glands (Oil glands) secrete an oily or wax-like secretion called **sebum.** It keeps the skin oily. Sebum removes some lipids like waxes, sterols, other hydrocarbons and fatty acids from the body.

Role of Liver in Excretion. Urea is formed in the liver which is eliminated through kidneys. Liver cells also degrade the haemoglobin of worn out red blood corpuscles into bile pigments (**bilirubin** and **biliverdin**). Liver cells also excrete cholesterol, certain products of steroid hormones, some vitamins and many drugs. Liver secretes these substances in the bile. The bile carries these substances to the intestine and are passed out with faeces.

Role of intestine in Excretion. The epithelial cells of the intestine (colon) excrete certain salts such as iron and calcium. These salts are eliminated with the faeces.

Role of Salivary glands in Excretion. Heavy metals and drugs are excreted in the saliva.

In aquatic animals like fish, gills remove carbon dioxide. Gills of many bony fish also excrete salt.

DISORDERS OF EXCRETORY SYSTEM

1. **Pyelonephritis.** It is an inflammation of the renal pelvis and the medullary tissue of the kidney. This disease is usually caused by bacteria that reach the kidney by way of the urethra and ureter. This disease usually affects counter current mechanism in the medulla. Affected person has inability to concentrate his urine. Symptoms of this disease are frequent and painful urination, fever and pain in the lumbar area. Prompt antibiotic treatment can cure the disease.

2. **Glomerulonephritis (Bright's disease).** It can be caused by the advance of pyelonephritis, by injury to the kidney, by congenital kidney defects or by an allergic reaction to the toxins of bacteria such as streptococci. The glomeruli become inflamed and engorged with blood. Proteins and red blood corpuscles enter the filtrate. Prompt antibiotic treatment may prevent permanent damage from an infection. If a large number of glomeruli become non-functional, the individual must use an artificial kidney.

3. **Hypertension caused by Secretion of Renin.** Secretion of large amounts of renin leads to the formation of angiotensin which in turn leads to hypertension.

4. **Renal calculi (Kidney Stones).** The stone gives rise to severe colic pain starting in the back

and radiating down to the front of the thigh or the testicle or vulva on that side. Stone or insoluble mass of crystallized salts (oxylates, etc.) is formed within kidney.

5. **Renal Tubular Acidosis.** In this condition the person is unable to secrete adequate quantities of hydrogen ions and as a result, large amounts of sodium bicarbonate are continuously lost into the urine.

6. **Oedema** (= Dropsy). Accumulation of excess fluid in tissues is called oedema. It is an increase in the volume of extracellular (interstitial) fluids without a change in their osmolality. It is usually caused by an excess of sodium ions, which in turn causes water retention.

7. **Uremia.** In this condition there are high concentrations of non-protein nitrogens which include urea, uric acid, creatinine and a few less important compounds. Urea accumulation in blood is comparatively high in uremia. In such patients urea can be removed by a process called **haemodialysis.**

8. **Renal Failure (RF) or Kidney Failure.** Renal failure is a decrease or cessation of glomerular filtration. In acute renal failure (ARF), both the kidneys abruptly stop working. The main feature of ARF is either **oligouria** (scanty urine production) which is daily urine output less than 250 ml or **anuria** (daily urine output less than 50 ml).

The causes are :— (i) Low blood volume (*e.g.*, due to haemorrhage). (ii) decrease cardiac output (iii) damaged renal tubules (iv) kidney stones (v) the dyes used to observe blood vessels in angiograms. (vi) non-steroid anti-inflammatory drugs and (vii) some antibiotic drugs.

The effects are :— (a) oedema, (b) potassium level rises which can lead to cardiac arrest, (c) no production of enough erythropoietin for adequate RBCs production and causing anaemia, (d) since kidneys are not able to convert vitamin D to calcitriol, which is needed for proper calcium absorption from the small intestine, (e) osteomalacia may also occur.

The treatment is Haemodialysis.

READ AND DIGEST

Types of Kidneys

- **Archinephric Kidney**. It is also called *ancestral kidney*. Such a kidney is found today in the larvae of certain cyclostomes (*e.g.*, myxine) but donot occur in any adult vertebrate.
- **Pronephric Kidney**. It appears as an embryonic functional kidney in cyclostomes, fishes and amphibians. It is retained throughout life in adult cyclostomes and a few bony fishes. It is also called *anterior kidney* due to its anterior position.
- **Mesonephric Kidney**. It is also called *middle kidney*. In lamprey, most adult fishes and amphibians, mesonephric kidney is functional both in embryo as well as adults. In reptiles, birds and mammals it is functional in embryos and is replaced by metanephric kidney in the adults.

  In sharks and caecilians (limbless amphibians) tubules extend posteriorly throughout the length of coelom, such a kidney is called a **opisthonephric kidney**.
- **Metanephric kidney**. It is also called *posterior kidney*. Metanephric kidneys are found in adult amniotes (reptiles, birds and mammals).
- **Gout** — High level of uric acid in the blood.
- Longest loop of Henle is found in Kangaroo rat.
- Kidneys are mesodermal in origin.
- **Dysuria** — painful urination.
- **Polyuria** — unusually large amounts of urine.
- **Oliguria** — scanty urine.
- **Anuria**— absence of urine.
- **Chordate** with flame cells — *Branchiostoma* (= Amphioxus).

- **Neural gland** is excretory gland in urochordates which opens into the pharynx.
- Desert living mammals have a long loop of Henle.
- Right human kidney is slightly lower than the left kidney because the liver pushes the kidney of its side down.
- The sweat glands in rabbit are mostly concentrated on the lips.
- **Nocturia** is a renal disease in which volume of urine rises so much at night that the person is compelled to wake up to ease out.
- Urine of a man suffering from diabetes insipidus is tasteless and watery.
- Loop of Henle is located in the medulla of kidney.
- Largest number of sweat glands in man are found on the palms.
- **Renal colic** is an excruciating pain on account of kidney stones. The incidence of kidney stones is slightly more in males than females.
- **Euryhaline** are those animals which tolerate wide range of salinity. **Stenohaline** animals live within a narrow range of salinity.

MULTIPLE CHOICE QUESTIONS

1. The reabsorption of glucose from the glomerular filtrate is due to
(1) high osmotic pressure of filtrate
(2) passive diffusion
(3) secondary active transport across the walls of proximal convoluted part
(4) filtration pressure exerted on the fluids in the loop of Henle

2. Physiologically urea is produced by the action of an enzyme
(1) uricase (2) urease
(3) arginase (4) none

3. Which of the following enzymes is produced in the kidneys?
(1) Rennin (2) Renin
(3) Uricase (4) Arginase

4. Glomeruli are mainly confined to
(1) Cortex (2) Medulla
(3) Pelvis (4) Pyramid

5. Blood fraction remaining unchanged after circulation through kidney is
(1) urea and uric acid
(2) urea and proteins
(3) urea and glucose
(4) glucose and proteins

6. Osmoregulation is the control over the
(1) *p*H of the blood
(2) removal of nitrogen from the body
(3) osmotic properties of cell membranes
(4) concentration of salts and water in the body

7. The osmoregulatory tissue in all animals is
(1) muscle (2) nervous
(3) epithelial (4) connective

8. Osmoconformers are the animal that
(1) actively control the osmotic condition of their body fluid
(2) do not actively control the osmotic condition of their body fluid
(3) maintain the condition of body fluid within a narrow osmotic range
(4) do not change the body fluid according to the osmolarity of ambient medium

9. The most important function of the mammalian kidney is the
(1) control of reproduction
(2) regulation of amount of protein in the blood
(3) control of amount of protein in the blood
(4) regulation of osmotic concentration of body fluid

10. Which of these is not a general function of the kidney?
(1) Regulation of blood volume
(2) Regulation of vitamin-A synthesis
(3) Regulation of solute concentration in the blood
(4) Regulation of the *p*H of the extracellular fluid

11. Kidney of a mammal resembles to the contractile vacuole of *Amoeba* in expelling out
(1) salts (2) glucose
(3) excess water (4) urea and uric acid

12. Consider the following statements
A. Flame cells are excretory structures in flatworms
B. Green glands are excretory organs in annelids
C. Columns of Bertini are the conical projections of renal pelvis into renal medulla between the renal pyramids
(1) B and C incorrect (2) A and B correct
(3) A and C correct
(4) A, B and C correct

13. In rabbit and humans, the kidney is
(1) pronephric (2) metanephric
(3) mesonephric (4) none of the above

14. The position of kidneys is
(1) retroperitoneal (2) interperitoneal
(3) intraperitoneal (4) none of these

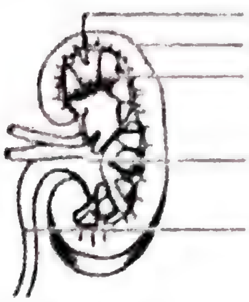
15. The retroperitoneal kidney is one covered by peritoneum on
(1) dorsal side (2) ventral side
(3) lateral side
(4) dorsal and ventral sides

16. The two kidneys of man lie
(1) at the same level
(2) at the level of ovaries
(3) left kidney at a higher level than the right one

(4) right kidney at a higher level than the left one

17. The layer of fibrous connective tissue that surrounds each kidney is
(1) renal sinus (2) renal pelvis
(3) renal capsule (4) perirenal fat

18. Refer the following diagram and identify the parts of a kidney indicated.



(1) A = cortex, B = nephron, C = pelvis, D = medulla, E = ureter
(2) A = nephron, B = cortex, C = medulla, D = ureter, E = pelvis
(3) A = nephron, B = cortex, C = medulla, D = pelvis, E = ureter
(4) A = nephron, B = ureter, C = pelvis, D = medulla, E= cortex

19. The part through which arteries and veins enter or leave the kidney is called
(1) hilum (2) renal pore
(3) major calyces (4) minor calyces

20. The cortex of the kidney contains
(1) hilum (2) glomeruli
(3) renal pelvis (4) renal pyramids

21. The broad commencement of ureter in the mammalian kidney is
(1) hilum (2) pelvis
(3) calyx (4) pyramid

22. Which of the following terms is used both for a part of kidney and a part of skeleton in the mammals?
(1) Pelvis (2) Cortex
(3) Medulla (4) Calyx

23. The columns of Bertini in the kidney of mammals are formed as extensions of
(1) pelvis in ureter (2) cortex in medulla
(3) medulla in cortex
(4) medulla in pelvis

24. Duct of Bellini opens into
(1) DCT (2) Ureter
(3) Renal pelvis (4) Collecting duct

25. The composition of ECF is regulated by
(1) brain (2) lungs
(3) thyroid (4) kidneys

26. Which is not correct with respect to human kidney?
(1) The peripheral region is called cortex and central medulla
(2) Malpighian corpuscles are present in the cortex region
(3) Blood leaves glomerulus through efferent venules
(4) The concave part of kidney is called hilum

27. Malpighian body is constituted by
(1) glomerulus only
(2) glomerulus and efferent vessel
(3) glomerulus and afferent vessel
(4) glomerulus and Bowman's capsule

28. The number of nephrons in a kidney is equal to
(1) the number of Bowman's capsules
(2) sum of Bowman's capsules and glomeruli
(3) double the number of Bowman's capsules
(4) sum of Bowman's capsules and Malpighian corpuscles

29. Which is true about the difference between cortical and juxtamedullary nephrons?
(1) Majority of nephrons are juxtamedullary
(2) Glomeruli and loops of Henle of cortical nephrons lie completely in cortex
(3) The afferent arterioles of the juxtamedullary nephrons give rise to most of vasa recta
(4) Cortical nephrons lack vasa recta

30. In a glomerulus, afferent
(1) arteriole has wider lumen than efferent arteriole
(2) arteriole has narrower lumen than efferent arteriole
(3) capillaries are thicker than efferent capillaries
(4) capillaries are thinner than efferent capillaries

31. Blood vessel draining the glomerulus in a mammalian nephron is called
(1) renal artery and is wider than the vessel entering it

(2) efferent arteriole and is wider than the vessel entering it
(3) efferent venule and is narrower than the vessel entering it
(4) efferent arteriole and is narrower than the vessel entering it

32. Inner layer of Bowman's capsule consists of
(1) podocytes (2) nephridia
(3) osteocytes (4) choanocytes
(Odisha JEE 2004, 11)

33. Brush border is characteristic of
(1) proximal convoluted tubule
(2) Bowman's capsule
(3) Glomerulus
(4) all of the above

34. In a mammalian kidney, loops of Henle are mainly located in
(1) pelvis (2) cortex
(3) medulla (4) major calyx

35. The animal that excretes amino acids without deamination is
(1) *Rana* (2) *Unio*
(3) *Earthworm* (4) *Labeo*

36. Which of the following is the most toxic nitrogenous waste?
(1) Carbon dioxide (2) Urea
(3) Uric acid (4) Ammonia

37. Which of the following is first formed nitrogenous waste of vertebrate?
(1) NH_3 (2) Carbon dioxide
(3) Alanine (4) Urea

38. With respect to the mode of excretion, which type of organism bony fishes are?
(1) Ureotelic (2) Uricotelic
(3) Ammonotelic (4) Osmoconformers

39. Frog's tadpoles are
(1) ureotelic (2) uricotelic
(3) aminotelic (4) ammonotelic

40. Shifting of ammonotelism to ureotelism is seen in
(1) Frog (2) Fishes
(3) Birds (4) Man

41. Ammonotelic animals are predominantly
(1) aerial (2) aquatic
(3) parasitic (4) terrestrial

42. Which animal is not ammonotelic?
(1) Whale (2) Bony Fishes
(3) Crocodile (4) Tadpole

43. Which one is most soluble in water?
(1) Urea (2) Cholesterol
(3) Uric acid (4) Fatty acids

44. Nitrogenous waste is excreted mainly as
(1) urea in both frog and tadpole
(2) uric acid in frog and urea in tadpole
(3) urea in frog and ammonia in tadpole
(4) urea in tadpole and ammonia in frog

45. Urea is the breakdown product of
(1) lipids (2) glucose
(3) fatty acids (4) amino acid

46. Excretion of nitrogenous waste product mainly as uric acid by birds is helpful in
(1) conserving water
(2) conserving body heat
(3) eliminating excess water
(4) eliminating excess body heat

47. Most insects are
(1) ureotelic (2) aminotelic
(3) ammonotelic (4) uricotelic

48. Excretion of nitrogenous waste product in semisolid form occurs in
(1) amniotes (2) aquatic animals
(3) ureotelic animals
(4) uricotelic animals

49. Uric acid is formed in human being from
(1) glucose (2) purines
(3) proteins (4) pyrimidines

50. Excretion of bile pigments in the urine indicates
(1) rickets (2) jaundice
(3) diabetes (4) anaemia

51. Removal of amino group of amino acid to transform it into keto acid is
(1) transamination (2) ammonification
(3) deamination (4) none of these

52. In man, the urea is mainly produced in
(1) liver (2) spleen
(3) kidneys (4) gall bladder

53. Ornithine cycle refers to the sequence of biochemical reactions taking place in the
(1) liver (2) kidney
(3) stomach (4) pancreas

54. In living organisms, ammonia is converted into urea through a metabolic cycle called
(1) arginine cycle (2) ornithine cycle
(3) fumarine cycle (4) citrulline cycle

55. Ornithine cycle was discovered by
(1) Ornithine (2) Calvin
(3) Watson
(4) Krebs and Henseleit

56. The urea is formed from an amino acid
(1) lysine (2) cysteine
(3) arginine (4) methionine

57. Amino acids participating in ornithine cycle are
(1) arginine, lysine and citrulline
(2) ornithine, arginine and glycine
(3) arginine, citrulline and ornithine
(4) ornithine, arginine and glutamic acid

58. To convert ammonia into urea, the liver cells require
(1) water (2) sulphur
(3) oxygen (4) carbon dioxide

59. Which enzyme is associated with production of urea?
(1) Urease (2) Arginase
(3) Aspartase (4) Glutaminase

60. What is true of urea biosynthesis?
(1) Uric acid is starting point
(2) Urea is synthesized in kidney
(3) Urea is synthesized in lysosomes
(4) Urea cycle enzymes are located inside mitochondria and cytosol

61. The stage of ornithine cycle at which arginase enzyme is used
(1) ornithine → urea
(2) arginine → ornithine
(3) ornithine → citrulline
(4) citrulline → arginosuccinic acid

62. If liver from body is removed then which component of blood would increase?
(1) Urea (2) Protein
(3) Uric acid (4) Ammonia

63. First step in urine formation is
(1) Ultrafiltration
(2) Tubular secretion
(3) Selective secretion
(4) Tubular reabsorption

64. Function of glomerulus in rabbit's kidney is
(1) blood filtration for urine formation
(2) reabsorption of salts
(3) urine collection
(4) all of the above

65. Which of the following will lead to an increase in glomerular fluid filtration in the kidney?
(1) An increase in the protein concentration in the plasma
(2) An increase in the fluid pressure in Bowman's space
(3) An increase in the glomerular capillary blood pressure
(4) A decrease in the glomerular capillary blood pressure

66. The glomerular filtrate *i.e.*, the liquid collected in the cavity of Bowman's capsule is
(1) plasma
(2) urine
(3) blood minus proteins
(4) blood minus proteins and corpuscles

67. In comparison to blood plasma, percentage of glucose in glomerular filtrate is
(1) nil (2) equal
(3) lower (4) higher

68. Which of the following is most likely to cause an increase in the glomerular filtration rate?
(1) Volume depletion
(2) Blockage of ureter
(3) Dilation of the afferent arterioles
(4) Release of Aldosterone from pituitary

69. If the diameter of the afferent renal arteriole is decreased and that of efferent renal arteriole is increased, the ultrafiltration will
(1) be faster (2) be slower
(3) not takes place
(4) take place with the same speed

70. When does glomerular filtration occurs in Bowman's capsule?
(1) When hydrostatic pressure of blood in the glomerulus is 70 mmHg and net filtrate pressure is – 25 mmHg
(2) When hydrostatic pressure of blood in the glomerulus is 70 mmHg and net filtrate pressure is – 35 mmHg
(3) When hydrostatic pressure of blood in the glomerulus is 75 mmHg and net filtrate pressure is 25 mmHg
(4) When hydrostatic pressure of blood in the glomerulus is 70 mmHg and net filtrate pressure is – 70 mmHg

71. Ultrafiltration occurs in a glomerulus when
(1) hydrostatic pressure exceeds osmotic pressure

(2) osmotic pressure exceeds hydrostatic pressure
(3) capsular hydrostatic pressure exceeds glomerular hydrostatic pressure
(4) colloidal osmotic pressure plus capsular pressure remain less than blood hydrostatic pressure

72. Total filtrate formed in 24 hours in human kidney is
(1) 1-2 litre (2) 8.0 litre
(3) 18 litre (4) 180 litre
(WB-JEE 2007, 11)

73. In human beings the capsular urine entering the Proximal Convoluted Tubule (PCT) is
(1) isotonic to blood
(2) hypotonic to blood
(3) isotonic to seawater
(4) hypertonic to blood

74. Which of these will be completely reabsorbed from glomerular filtrate under normal conditions in the nephrons?
(1) Urea (2) Salts
(3) Glucose (4) Uric acid

75. Most of the glucose that is filtered through the glomerulus undergoes reabsorption in
(1) distal tubule
(2) collecting duct
(3) proximal tubule
(4) ascending limb of the loop of Henle

76. Maximum absorption of Na^+ and K^+ ions occur in
(1) Loop of Henle
(2) Bowman's capsule
(3) Distal convoluted tubule
(4) Proximal convoluted tubule

77. In which of the following regions of nephron does maximum reabsorption of useful substances takes place?
(1) PCT (2) DCT
(3) Henle's loop (4) Glomerulus

78. If Henle's loop were absent from mammalian nephron, which of the following is to be expected?
(1) The urine will be more dilute
(2) There will be no urine formation
(3) The urine will have more concentration
(4) There will be hardly any change in the quality and quantity of urine formed

79. Part of nephron impermeable to salt is
(1) descending limb of loop of Henle
(2) ascending limb of loop of Henle
(3) distal convoluted tubule
(4) collecting ducts

80. The part of the nephron impermeable to water is
(1) distal tubule (2) collecting duct
(3) proximal tubule
(4) ascending limb of Henle's loop

81. Reabsorption of water through the tubules mainly occurs by
(1) osmosis
(2) active transport
(3) facilitated diffusion
(4) carrier transport

82. ADH will be released from the posterior pituitary when there is a decrease in plasma
(1) pH (2) volume
(3) sodium concentration
(4) osmotic pressure

83. In deficiency of ADH, rate of micturition
(1) increases (2) decreases
(3) remains the same
(4) none of these

84. Decreased level of ADH results in the production of
(1) isotonic urine (2) hypertonic urine
(3) hypotonic urine (4) none of these

85. Urine is concentrated with the help of
(1) ADH only (2) Aldosterone only
(3) Both of these (4) Urochrome

86. In the renal tubules the permeability of the distal convoluted tubule and collecting duct to water is controlled by
(1) renin (2) calcitonin
(3) vasopressin (4) growth hormone

87. Vasopressin stimulates reabsorption of water and reduction of urine secretion. Hence vasopressin in otherwise called
(1) angiotensin
(2) neurotransmitter
(3) antidiuretic hormone
(4) growth regulating substance

88. Diabetes insipidus is due to
(1) excess of insulin
(2) deficiency of insulin
(3) hyposecretion of hypothalamic hormone
(4) hypersecretion of pituitary hormone

89. Sodium reabsorption from the distal tubule will be increased if there is an increase in
(1) ADH
(2) plasma volume
(3) mean arterial pressure
(4) plasma potassium concentration

90. Which is mismatched?
(1) PCT - Absorption of Na^+ and K^+
(2) DCT - Absorption of glucose
(3) Bowman's capsule - Glomerular filtration
(4) Loop of Henle - Absorption of water

91. The juxtaglomerular cells of the ...... and the macula densa cells of the ...... form the juxtaglomerular apparatus.
(1) afferent arteriole, proximal convoluted tubule
(2) efferent arteriole, proximal convoluted tubule
(3) afferent arteriole, distal convoluted tubule
(4) vasa recta, distal convoluted tubule

92. Which one is an important constituent of renin angiotensinogen-aldosterone system?
(1) JGA cell (2) Plasma cell
(3) Glomerulus (4) Erythropoietin

93. Aldosterone stimulates sodium reabsorption and potassium secretion mainly in
(1) descending limb of the loop of Henle
(2) ascending limb of the loop of Henle
(3) proximal convoluted tubule
(4) distal convoluted tubule

94. Renin-angiotensin pathway mainly controls
(1) ultrafiltration (2) cardiac output
(3) blood pressure
(4) glucose reabsorption

95. The function of renin is
(1) degradation of angiotensinogen
(2) stimulation of corpus luteum
(3) to reduce blood pressure
(4) vasodilation

96. The function of angiotensin II is
(1) to enhance the water and sodium reabsorption from renal tubule
(2) stimulation of adrenal medulla to secrete aldosterone
(3) to decrease the heartbeat and dilate arterioles
(4) all of the above

97. Kidneys regulate the amount of
(1) salts (2) proteins
(3) enzymes (4) hormones

98. Which of the following substances is actively secreted into glomerular filtrate of the kidney tubule?
(1) Glucose (2) H^+
(3) Amino acids (4) Chloride ions

99. Match the excretory functions of Section I with the parts of the excretory system in Section II. Choose the correct combination from among the answers given

Section I (Functions)	Section II (Parts of excretory systems)
A Ultra filtration	1. Henle's loop
B Concentration of urine	2. Ureter
C Transport of urine	3. Urinary bladder
D Storage of urine	4. Malpighian corpuscle
	5. Proximal convoluted tubule

Answer codes :
(1) A = 4, B = 1, C = 2, D = 3
(2) A = 4, B = 3, C = 2, D = 1
(3) A = 5, B = 4, C = 1, D = 3
(4) A = 5, B = 4, C = 1, D = 2

100. Formation of hypertonic urine is mediated through
(1) eating salt free diet
(2) counter-current system
(3) increased water intake
(4) having small loop of Henle

101. The yellow colour of urine is due to
(1) urea (2) bilirubin
(3) uric acid (4) urochrome

102. The amount of urine output per day in a normal human being is
(1) 4-5 L (2) 1-2 L
(3) 3-4 L (4) 500-750 mL

103. Healthy human does not excrete out in his urine
(1) Glucose (2) Uric acid
(3) Creatinine
(4) B-complex vitamins

104. Which of the following blood vessel in mammals would normally carry largest amount of urea?
(1) Renal vein (2) Hepatic vein
(3) Hepatic artery (4) Hepatic portal vein

105. Which blood vessel carries least percentage of urea?
(1) Renal vein (2) Renal artery
(3) Pulmonary vein (4) Hepatic portal vein

106. A substance not secreted by renal tubule
(1) Glucose
(2) Para-aminohippuric acid
(3) Ammonia (4) Potassium ions

107. The urine on standing gives a pungent smell. It is due to conversion of
(1) uric acid into ammonia by ornithine cycle
(2) urea into ammonia by bacteria
(3) amino acids into ammonia
(4) all of the above

108. A condition of failure of kidney to form urine is called
(1) anuria (2) ketouria
(3) hematuria (4) creatinine

109. Diuresis is a condition characterized by
(1) increase in urine volume
(2) decrease in urine volume
(3) increased glucose excretion
(4) decrease in electrolyte balance

110. Which of the following will not lead to a diuresis?
(1) Excessive sweating
(2) Deficiency of ADH
(3) Deficiency of insulin
(4) Excessive water intake

111. Which one of the following statements is false?
(1) Presence of glucose in urine is glycosuria
(2) Presence of excess urea in blood is uraemia
(3) Presence of albumin in urine is albuminuria
(4) Presence of ketose sugar in urine is ketonuria

112. Presence of RBCs in urine is called
(1) pyuria (2) glycosuria
(3) haematuria (4) albuminuria

113. Glycosuria is the condition, where a man
(1) eats more sugar
(2) sugar is excreted in faeces
(3) has low sugar level in blood
(4) excretes sugar in urine
(DUMET 2009, WB-JEE 2010)

114. Glomerular filtrate is
1. formed continuously by the process of ultrafiltration occurring at Malpighian corpuscles, in which the blood cells and the colloidal macromolecules are not allowed to pass across the filtering surface
2. the electrolyte free fluid collected within the lumen of Bowman's capsule
3. the protein free fluid collected within the lumen of Bowman's capsule
4. formed by the process of selective reabsorption

Answer codes :
(1) 1, 2 and 3 are correct
(2) 1 and 2 are correct
(3) 2 and 4 are correct
(4) 1 and 3 are correct

115. Proximal convoluted tubule (PCT) is lined with
(1) cuboidal epithelium
(2) columnar epithelium
(3) simple squamous brush border epithelium
(4) simple cuboidal brush border epithelium

116. The renal fluid isotonic to the blood is found in the
(1) collecting duct and ascending limb
(2) descending limb and collecting duct
(3) distal convoluted tubule and ascending limb
(4) proximal convoluted tubule and distal convoluted tubule

117. Which of the following is recovered in the collecting duct of the nephron?
(1) Potassium (2) Water
(3) Glucose (4) Proteins

118. Identify the correctly matched pair
1. Uraemia - Excessive amount of urea
2. Hyperglycemia - Excess glucose in blood

3. Absence of factor VIII – Haemophilia
4. X-linked disorder - Glycosuria

Answer codes :

(1) 1 and 2 are correct
(2) 2 and 4 are correct
(3) 1 and 3 are correct
(4) 1, 2 and 3 are correct

119. If one litre of water is introduced in human blood,then
(1) BMR increases
(2) BMR decreases
(3) RBCs collapse and urine production decreases
(4) RBCs collapse and urine production increases

120. What is removed from the filtrate at loop of Henle?
(1) Water (2) Glucose
(3) Amino acids (4) Hormones

121. The characteristic that is shared by urea, uric acid and ammonia is/are
A. they are nitrogenous wastes
B. they all need very large amount of water for excretion
C. they all are equally toxic
D. they are produced in the kidneys
(1) A only (2) A and C
(3) A and D (4) A, C and D

122. Find the incorrect statement regarding mechanism of urine formation in man
(1) Tubular secretion takes place in the PCT also
(2) Aldosterone induces greater reabsorption of sodium
(3) The counter current systems contribute in diluting the urine
(4) The glomerular filtration rate is about 125 mL per minute

123. Which one of the following is correct with reference to haemodialysis?
(1) The dialysis unit has a coiled cellophane tube
(2) Anti-heparin is added prior to haemodialysis
(3) Nitrogenous wastes are removed by active transport
(4) Blood is pumped back through a suitable artery after haemodialysis

124. The average quantity of urea excreted in urine by man per day is
(1) 1–5 g (2) 25–30 g
(3) 1–1.5 L (4) 80g
(Kerala PMT 2010)

125. Select the correct statement
(1) the ascending limb of the Henle's loop extends as the DCT
(2) the Juxtamedullary nephrons have reduced Henle's loop
(3) vasa recta is well developed in cortical nephrons
(4) the glomerulus encloses the Bowman's capsule

126. The condition where urea accumulates in blood is
(1) glycosuria (2) uraemia
(3) Ketonuria (4) acidosis
(Kerala PMT 2011)

127. Glucose and amino acids are mainly reabsorbed in
(1) distal tubule (2) collecting duct
(3) loop of Henle (4) proximal tubule
(WB-JEE 2011)

128. The Bowman's capsule is mainly found in
(1) cortex (2) medulla
(3) renal pelvis (4) renal pyramid
(Odisha JEE 2011)

129. What is the correct sequence in Ornithine Cycle of urea formation?
(i) Ornithine (ii) Arginine
(iii) Arginosuccinic acid (iv) Urea
(v) Citrulline
Select the correct answer using the codes given below
Codes :
(1) (i), (ii), (iii), (v), (iv)
(2) (i), (v), (iii), (ii), (iv)
(3) (i), (v), (ii), (iii), (iv)
(4) (i), (iii), (v), (ii), (iv)

130. A fluorescent dye is utilized to 'tag' antidiuretic hormone receptors. The greatest concentration of dye is expected in which of the following structures?
(1) Proximal convoluted tubule
(2) Renal capillaries
(3) Loop of Henle
(4) Collecting duct

131. All of the following are true except

(1) Renin is secreted by Juxta glomerular cell
(2) Juxta-glomerular cells are present in afferent arterioles
(3) Renin causes conversion of Angiotensi-no-gen to Angiotensin
(4) Angiotensin II is a potent vasodilator

132. Which of the following is not secreted by the kidney?
(1) Renin (2) Angiotensin I
(3) Erythropoietin
(4) 1, 25 Dihydroxycholecalciferol

133. All of the following are true about actions of – ANF except
(1) decreased blood pressure
(2) causes vasoconstriction
(3) decreased sodium reabsorption
(4) increased sodium excretion

134. A person stranded in the desert faces the risk of severe dehydration. Which of the following will be maximally stimulated to prevent water loss?
(1) Anterior and posterior pituitary
(2) Adrenal cortex and thyroid gland
(3) Hypothalamus and adrenal gland
(4) Adrenal gland and anterior pituitary

135. Find out the correct statement about the loop of Henle
(1) The descending limb is permeable to electrolytes
(2) The descending limb is permeable to water
(3) The ascending limb is permeable to water
(4) The ascending limb is impermeable to electrolytes

136. Find the correct match of site and function of nephron

SITE	FUNCTION
(1) DCT	Reabsorption of Na^+ and K^+ from filtrate
(2) Descending of loop of Henle	Impermeable to water
(3) PCT	HCO_3^- absorption of filtrate
(4) Collecting duct	Massive reabsorption of H_2O & H^+, K^+ ions

137. There are three organisms A, B, C.
A has to excrete Urea
B has to excrete Uric acid
C has to excrete Ammonia
Which out of these 3 organisms will have the maximum urine output?
(1) C will produce more urine than B
(2) B will produce more urine than C
(3) B will produce more urine than A
(4) C will produce less urine than A

138. Find the correct statement regarding human kidney
(1) The Bowman's capsule, PCT and DCT form the renal corpuscle.
(2) Majority of nephrons are juxtamedullary nephrons
(3) The kidneys lie between T_{12} and L_3 vertebral level
(4) The coloumns of Bertini lie in the outer renal cortex area

139. Consider the following statements
For osmoregulation in aquatic medium
1. A freshwater fish has to drink water continuously
2. A marine bony fish has to drink water continuously
3. A freshwater fish produces copious urine, which is hypo-osmotic to blood
4. A marine fish produces scanty urine, which is hypo-osmotic to blood

Which of the statements given above is/are correct?
(1) 1 only (2) 4 only
(3) 1 and 4 (4) 2 and 3

140. The human kidney
(1) is responsible for the storage of nutrients such as glycogen
(2) produces more dilute urine when the collecting ducts become less permeable to water
(3) responds to antidiuretic hormone by increasing urine output
(4) get rid of urea from the body by secreting it into the descending arm of the loop of Henle.

141. While doing some experiment with *Amoeba proteus* in a culture medium, it was found that the contractile vacuole of the protozoan disappeared although the other organelles showed normal activity. This must have been most probably due to

(1) change in the temperature of the medium
(2) change in the pH of the medium
(3) dilution of the medium with tap water
(4) dilution of the medium with sea water

142. The nephron is a hollow, convoluted tube of cells. It is engineered to concentrate urine by removing water at which of the following sites?

I. Proximal convoluted tubule
II. Descending limb of the loop of Henle
III. Ascending limb of the loop of Henle

(1) I only (2) II only
(3) I and II only (4) I, II and III

143. A substance is present in concentration of 2 mg % in the afferent arteriole and zero mg % in efferent. Thus true about the substance is
(1) impermeable in loop ofHenle
(2) absorbed in PCT
(3) secreted in cortical nephrons
(4) freely filtered in glomerulus

144. NaCl is more in the interstitial fluid of renal medulla than of cortex because of
(1) cortical loss of Na^+
(2) counter current mechanism
(3) vasa – recta have increased blood
(4) proximal convoluted tubule is more permeable to Na^+

145. Water from the two tanks shown in the diagram was tested 3 hours after they were stocked with indicated animals. The predominant nitrogenous waste detected in Tank I and Tank II respectively would be

(1) Urea in both
(2) ammonia in both
(3) ammonia and urea
(4) urea and uric acid

146. Antidiuretic hormone has the most abundant receptors in the kidneys of
(1) frogs in tropical pond
(2) rabbits in a grass land
(3) spotted deer in moist evergreen forest.
(4) Kangaroo rats in deserts

147. All of the following are true regarding renal homeostasis except
(1) Renin is secreted by Juxta glomerular cells
(2) A fall in GFR can activate the JG cells to release renin which can stimulate the glomerular blood flow.
(3) It releases renin which converts angiotensinogen to angiotensin II
(4) Angiotensin II is a potent vasoconstrictor

148. Which of the following statements is correct?
(1) ADH– prevents conversion of angiotensinogen in blood to angiotensin
(2) Aldosterone – facilitates water reabsorption
(3) ANF– enhances sodium reabsorption
(4) Renin – causes vasodilation

149. The pH of human urine is approximately
(1) 1.5 (2) 7 (3) 6 (4) 7.5

150. Which one of the following statements is incorrect?
(1) Birds and land snails are uricotelic animals
(2) Mammals and frogs are ureotelic animals
(3) Aquatic amphibians and aquatic insects are ammonotelic animals
(4) Birds and reptiles are ureotelic

151. Which of the following pairs is wrong?
(1) Uricotelic - - - - - - - - Birds
(2) Ureotelic - - - - - - - - Insects
(3) Ammonotelic - - - - - Tadpole
(4) Ureotelic - - - - - - - - Elephant

152. Which one of the following statements is incorrect?
(1) The medullary zone of kidney is divided into a few conical masses called medullary pyramids projecting into the calyces.
(2) Inside the kidney the cortical region extends in between the medullary pyramids as renal pelvis.
(3) Glomerulus alongwith Bowman's capsule is called the renal corpuscle
(4) Renal corpuscle, proximal convoluted tubule (PCT) and distal convoluted tubule (DCT) of the nephron are situated in the cortical region of kidney.

153. Match the terms given in Column I with their physiological processes given in Column II and choose the correct answer

Column I	Column II
A. Proximal convoluted tubule	i. Formation of concentrated urine
B. Distal convoluted tubule	ii. Filtration of blood
C. Henle's loop	iii. Reabsorption of 70-80% of electrolytes
D. Counter-current mechanism	iv. Ionic balance
E. Renal corpuscle	v. Maintenance of concentration gradient in medulla

(1) A – (iii), B – (v), C – (iii), D – (ii), E – (i)
(2) A – (iii), B – (iv), C – (i), D – (v), E – (ii)
(3) A – (i), B – (iii), C – (ii), D – (v), E – (iv)
(4) A – (iii), B – (i), C – (iv), D – (v), E – (ii)

154. Match the abnormal conditions given in Column A with their explanations, given in Column B and Choose the correct option

Column A	Column B
A. Glycosurea	(i) Accumulation of uric acid in joints
B. Renal calculi	(ii) Inflammation in glomeruli
C. Glomerular nephritis	(iii) Mass of crystallised salts within the kidney
D. Gout	(iv) Presence of glucose in urine

(1) A – (i), B – (iii), C – (ii), D – (iv)
(2) A – (iii), B – (ii), C – (iv), D – (i)
(3) A – (iv), B – (iii), C – (ii), D – (i)
(4) A – (iv), B – (ii), C – (iii), D – (i)

155. Dialysing unit (artificial kidney) contains a fluid which is almost same as plasma except that it has

(1) High glucose (2) High urea
(3) No urea (4) High uric acid

*156. Which one of the following four secretions is correctly matched with its source, target and nature of action?

	SECRETION	SOURCE	TARGET	ACTION
A	*Gastrin*	Stomach lining	Oxyntic cells	Production of HCl
B	*Inhibin*	Sertoli cells	Hypothalamus	Inhibition of secretion of gonadotropin releasing hormone.
C	*Enterokinase*	Duodenum	Gall bladder	Release of bile juice.
D	*Atrial Natriuretic Factor(ANF)*	Sinu atrial node (SAN)	Juxtaglom — erular apparatus (JGA)	Inhibition of release of renin

157. Which one of the following statements is correct with respect to salt-water balance inside the body of living organisms?

(1) When water is not available camels do not produce urine but store urea in tissues.
(2) Salmon fish excretes lot of stored salt through gill membrane when in fresh water.
(3) Paramoecium discharges concentrated salt solution by contractile vacuoles
(4) The body fluids of fresh water animals are generally hypotonic to surrounding water *(AIIMS – 2010)*

158. Find out the correct statement about the loop of Henle

(1) The descending limb is permeable to electrolytes
(2) The descending limb is permeable to water
(3) The ascending limb is permeable to water

*156. ANF is produced by atrial muscle fibres. In the question, source mentioned is SA node. But still this is the best option. Inhibin is produced by Sertoli cells in males and granulosa cells in females. It has mainly negative feedback effect on anterior pituitary (Guyton has also mentioned a possible feedback effect on hypothalamus).

(4) The ascending limb is impermeable to electrolytes (AIIMS – 2011)

159. A terrestrial animal must be able to
(1) actively pump salts out through the skin
(2) excrete large amounts of salts in urine
(3) excrete large amounts of water in urine
(4) conserve water

160. In ornithine cycle, which of the following wastes are removed from the blood?
(1) CO_2 and ammonia
(2) Ammonia and urea
(3) CO_2 and urea (4) Urea and urine

161. The net pressure gradient that causes the fluid to filter out of the glomeruli into the capsule is
(1) 20mm Hg (2) 50 mm Hg
(3) 75mm Hg (4) 30mm Hg

162. Earthworms are
(1) Ureotelic when plenty of water is available
(2) Uricotelic when plenty of water is available
(3) Uricotelic under conditions of water scarcity
(4) Ammonotelic when plenty of water is available

163. Angiotensinogen is a protein produced and secreted by
(1) Macula densa cells
(2) Endothelial cells (cells lining the blood vessels)
(3) Liver cells
(4) Juxtaglomerular (JG) cells

164. What will happen if the stretch receptors of the urinary bladder wall are totally removed?
(1) Urine will continue to collect normally in the bladder
(2) There will be no micturition
(3) Urine will not collect in the bladder
(4) Micturition will continue

(CBSE PRELIMS – 2009)

165. Uric acid is the chief nitrogenous component of the excretory products of
(1) Cockroach (2) Frog
(3) Man (4) Earthworm

(CBSE PRELIMS – 2009)

166. Which one of the following statements in regard to the excretion by the human kidneys is correct?
(1) Ascending limb of Loop of Henle is impermeable to electrolytes
(2) Descending limb of Loop of Henle is impermeable to water
(3) Distal convoluted tubule is incapable to reabsorbing HCO_3^-
(4) Nearly 99 per cent of the glomerular filtrate is reabsorbed by the renal tubules

(CBSE PRELIMS – 2010)

167. The principal nitrogenous excretory compound in humans is synthesized
(1) in the liver, but eliminated mostly through kidneys
(2) in kidneys but eliminated mostly through liver
(3) in kidneys as well as eliminated by kidneys
(4) in liver and also eliminated by the same through bile (CBSE PRELIMS – 2010)

168. Consider the following four statements regarding kidney transplant and select the *two correct* ones out of these.
(i) Even if a kidney transplant is proper the recipient may need to take immunosuppresants for a long time.
(ii) The cell-mediated immune response is responsible for the graft rejection
(iii) The B-lymphocytes are responsible for rejection of the graft.
(iv) The acceptance or rejection of a kidney transplant depends on specific interferons

The two *correct* statements are
(1) (i) and (ii) (2) (ii) and (iii)
(3) (iii) and (iv) (4) (i) and (iii)

(CBSE PRELIMS – 2010)

169. Which one of the following is not a part of a renal pyramid?
(1) Peritubular capillaries
(2) Convoluted tubules
(3) Collecting ducts
(4) Loop of Henle (CBSE PRELIMS – 2011)

170. Which one of the following correctly explains the function of a specific part of a human nephron?
(1) *Podocytes* : Create minute spaces (slit pores) for the filtration of blood into the Bowman's capsule.
(2) *Henle's loop* : most reabsorption of the major substances from the glomerular filtrate

(3) *Distal convoluted tubule* : reabsorption of K^+ ions into the surrounding blood capillaries

(4) *Afferent arteriole* : carries the blood away from the glomerulus towards renal vein (CBSE PRELIMS – 2011)

171. Which one of the following statements is correct with respect to kidney function regulation?
(1) When someone drinks lot of water, ADH release is suppressed.
(2) Exposure to cold temperature stimulates ADH release
(3) An increase in glomerular blood flow stimulates formation of Angiotensin II
(4) During summer when body loses lot of water by evaporation, the release of ADH is suppressed (CBSE PRELIMS – 2011)

172. The maximum amount of electrolytes and water (70 – 80 percent) from the glomerular filtrate is reabsorbed in which part of the nephron?
(1) Distal convoluted tubule
(2) Proximal convoluted tubule
(3) Descending limb of loop of Henle
(4) Ascending limb of loop of Henle (CBSE PRELIMS – 2012)

173. Which one of the following characteristics is common both in humans and adult frogs?
(1) Nucleated RBCs
(2) Ureotelic mode of excretion
(3) Four-chambered heart
(4) Internal fertilisation (CBSE MAINS – 2012)

174. A fall in glomerular filtration rate (GFR) activates
(1) Adrenal medulla to release adrenaline
(2) Posterior pituitary to release vasopressin
(3) Juxta glomerular cells to release renin
(4) Adrenal cortex to release aldosterone (CBSE MAINS – 2012)

175. Kidneys perform all the functions except
(1) filtration of blood
(2) regulation of B.P.
(3) secretions of antibodies
(4) regulation of *p*H in body fluid (CHD. CET – 2012)

176. A healthy adult human excretes out (on the average) how many grams of urea per day?
(1) 25 – 30 g (2) 40 – 50 g
(3) 10 – 15 g (4) None of the above (H.P. PMT – 2010)

177. Dialysis fluid contains all the constituents as in plasma *except*
(1) Electrolytes (2) Proteins
(3) Nitrogenous wastes
(4) All the above (H.P. PMT – 2011)

178. The Juxta glomerular cells of kidney produce a peptide hormone called
(1) Gastrin (2) Secretin
(3) Erythropoietin (4) Estradiol (H.P. PMT – 2011)

179. Erythropoietin stimulates
(1) Osmoregulation
(2) Formation of RBC
(3) Reduces blood pressure
(4) Gastric inhibitory peptide (H.P. PMT – 2012)

180. Urea synthesis takes place primarily in liver because
(1) NH_3 and CO_2 are present in liver only
(2) hormone ADH is found in liver only
(3) enzyme arginase is present in liver only
(4) kidney is smaller than liver (DUMET – 2010)

181. Which substance is in higher concentration in blood than in glomerular filtrate ?
(1) Plasma proteins (2) Urea
(3) Water (4) Glucose (Karnataka CET 2009)

182. A large quantity of fluid is filtered every day by the nephrons in the kidney. Only about 1% of it is excreted as urine. The remaining 99% of the filtrate
(1) gets collected in the renal pelvis
(2) is lost as sweat
(3) is absorbed into the blood
(4) is stored in the urinary bladder (Karnataka CET 2009)

183. Vasa recta and network of blood capillaries occur in association with
(1) Digestive system (2) Liver lobule
(3) Renal tubules
(4) Skin (MHT CET 2009)

184. Which is not part of glomerular ultrafiltrate ?
(1) Bowman's capsule (2) RBC
(3) Amino acids
(4) Minerals (MHT CET 2009)

185. Choose the animals which are not ureotelic ?
(1) Tadpole (2) Crab
(3) Labeo (4) All of these
(MHT. CET 2009)

186. ADH deficiency shows the following condition
(1) only polydipsia (2) polyuria
(3) polydipsia and polyuria
(4) glucosuria *(J & K CET 2011)*

187. Glucose and amino acids are reabsorbed in the
(1) proximal tubule (2) distal tubule
(3) collecting duct (4) loop of Henle
(West Bengal JEE 2011)

188. Functional unit of kidney is
(1) neuron (2) axon
(3) glomerulus (4) nephron
(Odisha JEE 2012)

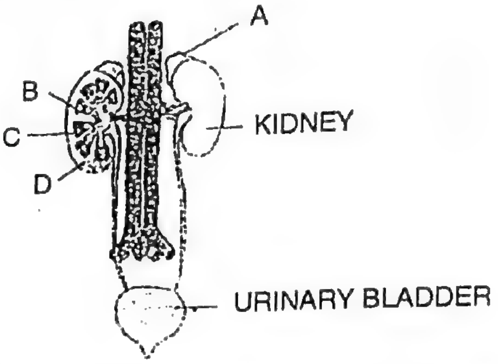
189. Which of the following glands does not help in excretion ?
(1) Liver (2) Sweat glands
(3) Pancreas (4) Both (1) and (3)
(Odisha JEE 2012)

190. Which of the following is excreted in human urine ?
(1) Ammonia (2) Urea
(3) Uric acid (4) Amino acid
(Odisha JEE 2012)

191. A fall in glomerular filmation rate (GFR) activates
(1) Juxta glomerular cells to release renin
(2) Adrenal cortex to release aldosterone
(3) Adrenal medulla to release adrenaline
(4) Posterior pituitary to release vasopressin
(Odisha JEE 2012)

192. Loop of Henle is found in
(1) lung (2) liver
(3) neuron (4) nephron
(AMU 2012)

*193. Figure shows human urinary system with structures labelled A to D. Select option which correctly identifies them and gives their characteristics and/or functions.



(1) C- Medulla – inner zone of kidney and contains complete nephrons.
(2) D-Cortex-outer part of kidney and do not contain any part of nephrons.
(3) A – Adrenal gland –located at the anterior part of kidney. Secrete Catecholamines which stimulate glycogen breakdown.
(4) B-Pelvis-broad funnel shaped space inner to hilum, directly connected to loops of Henle. *(NEET – 2013)*

194. Which of the following causes an increase in sodium reabsorption in the distal convoluted tubule?
(1) Decrease in antidiuretic hormone levels
(2) Increase in aldosterone levels
(3) Increase in antidiuretic hormone levels
(3) Decrease in aldosterone levels
(AIPMT 2014)

195. Which of the following does **not** favour the formation of large quantities of dilute urine?
(1) Caffeine
(2) Renin
(3) Atrial-natriuretic factor
(4) Alcohol
(AIPMT 2015)

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*193. The correct labelling of
A – Adrenal gland
B and C – Medullary pyramids / Medulla.
D – Cortex
(1) False; as medulla contains the loop of Henle of nephrons; the malpighian corpuscle, PCT & DCT of nephron are situated in the cortex.
(2) False; as cortex contains the malpighian corpuscle, PCT and DCT.
(3) True; although adrenal gland is located super anterior to upper end of the kidney, but no other option is correct, therefore we consider this statement to be correct.
(4) False; (2) is medullary Pyramid.

*196. Removal of proximal convoluted tubule from the nephron will result in
(1) more concentrated urine
(2) no change in quality and quantity of urine
(3) no urine formation
(4) more diluted urine *(AIPMT 2015)*

197. Human urine is usually acidic because
(1) the sodium transporter exchanges one hydrogen ion for each sodium ion, in peritubular capillaries.
(2) excreted plasma proteins are acidic.
(3) potassium and sodium exchange generates acidity.
(4) hydrogen ions are actively secreted into the filtrate *(AIPMT Retest 2015)*

198. In mammals, which blood vessel would normally carry largest amount of urea?
(1) Dorsal Aorta (2) Hepatic Vein
(3) Hepatic Portal Vein
(4) Renal Vein *(AIPMT/NEET 2016)*

199. The part of nephron involved in active reabsorption of sodium is
(1) Distal convoluted tubule
(2) Proximal convoluted tubule
(3) Bowman's capsule
(4) Descending limb of Henle's loop *(NEET-2-2016)*

200. Which of the following statements is correct?
(1) The ascending limb of loop of Henle is impermeable to water.
(2) The descending limb of loop of Henle is impermeable to water.
(3) The ascending limb of loop of Henle is permeable to water.
(4) The descending limb of loop of Henle is permeable to electrolytes *(NEET 2017)*

201. A decrease in blood pressure/volume will not cause the release of
(1) Renin
(2) Atrial Natriuretic Factor
(3) Aldosterone
(4) ADH *(NEET 2017)*

*195. Since PCT absorbs about 70% of filtered water and maximum reabsorption of water takes place in this part of nephron; thus removal of it will lead to increased quantity of dilute urine.

ANSWERS

1. (3)	2. (3)	3. (2)	4. (1)	5. (4)	6. (4)	7. (3)	8. (2)	9. (4)	10. (2)
11. (3)	12. (1)	13. (2)	14. (1)	15. (2)	16. (3)	17. (3)	18. (3)	19. (1)	20. (2)
21. (2)	22. (1)	23. (2)	24. (3)	25. (4)	26. (3)	27. (4)	28. (1)	29. (4)	30. (1)
31. (4)	32. (1)	33. (1)	34. (3)	35. (2)	36. (4)	37. (1)	38. (3)	39. (4)	40. (1)
41. (2)	42. (1)	43. (1)	44. (3)	45. (4)	46. (1)	47. (4)	48. (4)	49. (2)	50. (2)
51. (3)	52. (1)	53. (1)	54. (2)	55. (4)	56. (3)	57. (3)	58. (4)	59. (2)	60. (4)
61. (2)	62. (4)	63. (1)	64. (1)	65. (3)	66. (4)	67. (2)	68. (3)	69. (2)	70. (3)
71. (4)	72. (4)	73. (1)	74. (3)	75. (3)	76. (4)	77. (1)	78. (1)	79. (1)	80. (4)
81. (1)	82. (2)	83. (1)	84. (3)	85. (3)	86. (3)	87. (3)	88. (3)	89. (4)	90. (2)
91. (3)	92. (1)	93. (4)	94. (3)	95. (1)	96. (1)	97. (1)	98. (2)	99. (1)	100. (2)
101. (4)	102. (2)	103. (1)	104. (2)	105. (1)	106. (1)	107. (2)	108. (1)	109. (1)	110. (1)
111. (4)	112. (3)	113. (4)	114. (4)	115. (4)	116. (4)	117. (2)	118. (4)	119. (4)	120. (1)
121. (1)	122. (3)	123. (1)	124. (2)	125. (1)	126. (2)	127. (4)	128. (1)	129. (2)	130. (4)
131. (4)	132. (2)	133. (2)	134. (3)	135. (2)	136. (3)	137. (1)	138. (3)	139. (4)	140. (2)
141. (4)	142. (3)	143. (4)	144. (2)	145. (3)	146. (4)	147. (3)	148. (2)	149. (3)	150. (4)
151. (2)	152. (2)	153. (2)	154. (3)	155. (3)	156. (4)	157. (1)	158. (2)	159. (4)	160. (1)
161. (1)	162. (4)	163. (3)	164. (2)	165. (1)	166. (4)	167. (1)	168. (1)	169. (2)	170. (1)
171. (1)	172. (2)	173. (2)	174. (3)	175. (3)	176. (1)	177. (3)	178. (3)	179. (2)	180. (3)
181. (1)	182. (3)	183. (3)	184. (2)	185. (4)	186. (3)	187. (1)	188. (4)	189. (3)	190. (2)
191. (1)	192. (4)	193. (3)	194. (2)	195. (2)	196. (4)	197. (4)	198. (2)	199. (1, 2)	200. (1)
201. (2)									

Chapter

20 Locomotion and Movement

THEORY–a quick rundown

The voluntary movement of an individual from one place to another is called **locomotion.**

Types of Movement

Although movement varies greatly, yet it involves three basic mechanisms.

1. Amoeboid Movement (= Pseudopodial movement). This type of movement is found in leucocytes (phagocytes and macrophages of the human lymphatic system).

2. Ciliary movement. Cilia of the upper respiratory tract of humans keep the invading microbes and dust particles out. Whereas the cilia of the Fallopian tube (= oviduct) and vasa efferentia of human females and males transport ova and spermatozoa respectively.

Flagellar Movement. An enlarged version of cilium is known as **flagellum**. Sperms of various animals move with the help of flagella.

3. Muscular Movement. This is used in the majority of vertebrates, including humans. The universal property of this mechanism is to exert a force by alternate contraction and relaxation.

Cyclosis. Streaming movement of protoplasm to distribute the material inside the cell is called cyclosis.

The movements in higher vertebrates including humans involve muscles, skeleton and joints.

MUSCLES

Types of Muscles

In humans, muscles constitute about 40 to 50 percent of the total body weight. In humans muscles are broadly classified into three categories. (1) Skeletal or striped or striated or voluntary muscles. (2) Visceral or smooth or unstriped or nonstriated or involuntary muscles. (3) *Cardiac muscles*. Structure, location and functions of these muscles have been described in details in the Chapter 'Animal tissues'.

1. Skelatal Muscles (= Striated muscles). These muscles are normally attached to the skeleton. Each muscle consists of numerous fibres. Each muscle fibre is an elongated cell surrounded externally by a delicate membrane, the **sarcolemma**. Just beneath the sarcolemma in each fibre many nuclei occur at irregular intervals. Thus, these fibres are multi-nucleated or **syncytial** in nature. The cytoplasm of each fibre (**sarcoplasm**) has a large number of **myofibrils**. Each myofibril shows **dark** and **light bands** of stripes alternating with each other.

These muscles are found in the muscle of limbs, body walls, tongue, pharynx and beginning of oesophagus and are under the control of animal's will.

The dark bands of the myofibril are termed the **A-bands (Anisotropic bands)**. Each band has at its middle a **light zone** called **H-zone** (**Henson's zone**). **M-line** is present in the centre of H-zone. The light bands are also called **I-bands (Isotropic bands)**. Each I-band has at its centre a dark membrane termed the **Krause's membrane** or **Dobie's line** or **Z disc** or **Z-line (Zwischenscheibe line).** The sarcolemma is invaginated to form **T-tubules (Transverse tubules).** The T-tubules are present at the level of Z-line. The T-tubules form a simple mechanism of transportation of nutrients and carry the signals for contraction of the myofibrils from the sarcolemma to the interior. The part of the myofibril between two successive Z-lines is called **sarcomere**. Therefore, the sarcomere comprises A-band and half of each adjacent I-band. In fact each sarcomere is a bundle of **thick** and **thin** myofilaments. The thick myofilaments are confined to the A-bands only. They are thick and free at both the ends. The thick myofilaments are composed of **myosin** (protein). The thin **myofilaments** occur in I-bands but they also extend for some distance into the A-bands between the thick **myofilaments**. They are thinner and are attached to the Z-lines by one end, however, the other end is free. The thin myofilaments are composed of three different proteins : **actin, tropomyosin** and **troponin.** The actin and myosin help in the contraction or shortening of muscle. Thus, the *sarcomere is the functional unit of the contractile system in muscle.*

These muscles are under the control of animal's will.

2. **Visceral Muscles (= Smooth Muscles).** These are elongated and spindle shaped. Each muscle fibre contains a single oval nucleus surrounded by the cytoplasm (sarcoplas). In the cytoplasm the myofibrils are arranged longitudinally. There is no sarcolemma, however, the fibre is encolsed by plasma membrane.

Smooth muscles are found in the posterior part of oessophagus, stomach, intestine, lungs, urinogenital tract, urinary bladder, blood vessels, iris of eye, dermis of skin and arrector pili muscle of hair.

These muscles help in **peristalsis** which happens in tubular viscera. Action of these muscles is controlled by autonomic nervous system and hence they are not under the controls of the animal's will.

3. **Cardiac muscles.** These muscles show the characters of both unstriped and striped muscles. Each muscle fibre is a long and cylindrical structure which lacks a definite sarcolemma. The fibres are **uninucleate**. The fibres have some lateral branches, known as **cross bridges** to form a contractile network. The myofibrils have transverse faint dark and light bands, which alternate with each other. In this way cardiac muscle firbres are also striped, but having dark **intercalated discs** at intervals. The intercalated discs function as boosters of contraction wave and permit the wave of muscle contraction to be transmitted from one cardiac fibre to another.

The muscles are found in the wall of heart and have very rich blood supply.

Cardiac muscle fibres are supplied with both central and autonomic nervous synstem and are not under the control of the will of the animal. However, these muscles never get fatigued. Blood capillaries penetrate the cardiac muscle fibres. They have very rich blood supply. They have the property of contraction, even when they are isolated from the body temporarily.

Structure of Contractile Proteins

As mentioned above, the sarcomere is the functional unit of myofibril. The part of the myofibril between two successive Z-lines is called sarcomere. The sarcomere consists of thick and thin myofilaments.

(i) Thick Myofilaments (= Myosin filaments)

Each myosin (thick) myofilament is a polymerised protein made of many monomeric proteins called **meromyosins**. Each meromyosin has two important parts, a globular head with a short arm and a tail, the former is called the heavy meromyosin (HMM) and the latter called the light meromyosin (LMM). The HMM component projects outwards at an angle from a polymerized myosin filament at regular distance and known as **cross arms**. The globular head is an active ATPase enzyme and has binding sites for ATP and active sites for actin.

(ii) Thin Myofilaments (= Actin filaments)

Each actin (= thin) myofilament is composed of three different proteins— actin, tropomyosin and troponin.

(a) **Actin**. Actin is a globulin protein and has low molecular weight. It occurs in two forms, the monomeric G-actin and the polymeric F-actin. **G-actin** (G = globular) polymerizes to the fibrous form **F-actin** (F = fibrous) in the presence of Mg^{++}.

(b) **Tropomyosin**. Tropomyosin is a double stranded α-helical rod. It is fibrous molecule that attaches to F-actin in the groove between its filaments. In the resting state, the tropomyosin molecules are believed to lie on top of the active sites of the actin strands so that attraction cannot occur between the actin and myosin to cause contraction.

(c) **Troponin.** Troponin is a complex of 3 polypeptides. **Troponin T** (TpT) binds to tropomyosin as well as to the other two troponin components. **Troponin I** (TpI) inhibits the F-actin-myosin interaction and also binds to other components of troponin. **Troponin C** (TpC) is a calcium-binding polypeptide. The strong affinity of the troponin for calcium ions is believed to initiate the contraction process.

The major component of muscle is water. **Potassium** is the most abundant mineral element in muscle. Other minerals such as sodium, calcium, phosphorus and magnesium are present only in traces. Muscles store **glycogen**. They have oxygen carrying pigment **myoglobin** or "muscle haemoglobin". Muscles also contain ATP, phosphocreatine, creatine, urea, etc.

MECHANISM OF MUSCLE CONTRACTION

The contraction of skeletal muscle includes ultrastructural and biochemical events.

1. **Ultrastructural events (Biophysics of muscle contraction). H.E. Huxley** and **A.F. Huxley** and **Ralph** in 1954 proposed a theory, known as **sliding filament theory,** to explain the process of muscular contraction, which is now generally accepted. This theory states that the thin myofilaments slide over the thick myofilaments to penetrate deeper into the A bands in the contracting muscle fibre. The thin myofilaments meet in the centre of the sarcomere. As such the width of the A band remains constant. However, the I bands shorten and ultimately disappear. This shortens the sarcomere. As all the sacromeres of the myofibril shorten simultaneously the muscle fibre shortens. However, the myofilaments do not undergo any alteration in length. It is thought that the cross bridges on the thick myofilaments might pull the thin myofilaments while muscle is contracted, but during relaxation these crossbridges disappear. Thus contraction and relaxation of muscles are brought about by the repetitive formation and breakage of crossbridges respectively.

The proteins, **troponin** and **tropomyosin**, which are closely associated with actin, are also important in regulating the attachment of actin to the crossbridges.

2. **Biochemical events (Biochemistry of muscle contraction). Albert Szent Gyorgyi** and others worked out the biochemical events associated with the muscle contraction. These biochemical events are summarised below.

(i) The nerve impulse stimulates a muscle fibre at the **neuromuscular junction** or **motor end plate**, producing **acetylcholine.**

(ii) Acetylcholine brings out the release of calcium ions from the sarcoplasmic reticulum of the muscle into the interior of muscle fibre.

(iii) Myosin now binds with actin to form **actomyosin** in the presence of ATP and calcium ions.

(iv) Energy for muscle contraction is provided by hydrolysis of ATP by **myosin ATP-ase enzyme.** This hydrolysis produces ADP, inorganic phosphate and energy (used in muscle contraction). **Phosphocreatine** donates its high energy and phosphate to ADP, producing ATP. Phosphocreatine is again formed in relaxing muscle by using ATP produced by carbohydrate oxidation.

(v) At the end of muscle contraction, the conversion of ADP into ATP takes place. The muscle is rich in glycogen which is broken down into lactic acid through a series of reactions **(glycolysis)** and liberates energy. The reactions taking place in the muscles and liver, are proposed by Cori and Cori, hence known as **Cori's cycle**. Cori and Cori got Nobel Prize with Houssay in 1947

Important Human Muscles

Muscles	Location	Muscles	Location
Biceps and triceps	upper arm	Rectus abdominis	lower abdomen
Deltoid	shoulder	Gluteus maximus	buttock
Latissimus	shoulder	Gastrocnemius	shank
Trapezius	upper back and each side of neck	Stapedius	middle ear
		Quadriceps femoris	thigh
Pectolaris major	chest	Oblique	eye
Pectolaris minor	chest	Rectus	eye
External oblique	lower abdomen	Maxillaris	upper jaw
Internal oblique	lower abdomen	Mandibularis (Masseter)	lower jaw

Classification of Muscles According to Function

1. **Flexor.** This muscle bends one part of a limb on another at a joint, *e.g.*, **biceps**. It brings the fore arm towards the upper arm.
2. **Extensor.** Extends or straightens a limb, *e.g.*, **triceps**. It extends the fore arm.
3. **Adductor.** Brings a limb towards the mid line of the body, *e.g.*, **latissimus dorsi**. It presses the entire arm against the side.
4. **Abductor.** Pulls a limb away from the mid-line of the body, *e.g.*, **deltoideus**. It draws the entire arm to the side.
5. **Pronator.** This muscle turns the palm downward or to the posterior, *e.g.*, **pronator teres.**
6. **Supinator.** This muscle turns the palm upward or to the anterior, *e.g.*, **supinator.**
7. **Elevator.** Raises a part of the body, *e.g.*, **masseter**. It lifts up the lower jaw to close the mouth.
8. **Depressor.** It lowers a part of the body, *e.g.*, **depressor mandibulae**. It lowers down the lower jaw to open the mouth.
9. **Rotator.** Rotates a part of the body, *e.g.*, **pyriformis**. It raises and rotates the thigh.
10. **Sphincter.** Decreases the size of an opening, *e.g.*, **pyloric sphincter** between stomach and duodenum.
11. **Dilator.** This muscle enlarges the size of an opening.

12. **Invertor** and **evertor** turn the sole inwards and outwards respectively.

13. **Antagonistic Muscles.** They act in opposition to other muscles. The biceps, for example, bends the arm and is called a **flexor**. Its antagonist, the **triceps** extends the arm and is termed as **extensor.**

Molecular components of muscles. These are (i) contractile proteins (*e.g.*, myosin, actin, tropomysin, and troponin), (ii) enzymes, (iii) fats and carbohydrates, (iv) organic phosphates (*e.g.*, adenosine triphosphate (ATP) and phosphocreatine) and (v) ions of sodium, potassium, magnesium, calcium and chloride. **Potassium is the most abundant mineral in muscles.**

Motor unit. A motor unit consists of a single motor neuron (nerve cell) and the muscle fibres it innervates.

Single muscle twitch. Single isolated contraction of muscle fibre is called single muscle twitch.

Threshold stimulus. For contraction, muscle fibre always requires a specific minimum strength or intensity of the stimulus or nerve impulse. This is called threshold stimulus.

All or none law (= Bowditch's law). According to this law when a fibre contracts, it contracts maximally.

Summation. Addition of one contraction to a previous one to produce greater shortening is called summation.

Rigor mortis. The rigidity of muscles that occurs after death is called rigor mortis.

Isotonic contraction and **Isometric contraction.** The force produced by a whole muscle when it contracts is called muscle **tension**. When the tension remains the same whereas the change occurs in the length of the muscle fibres, it is termed **isotonic** (same tension) **contraction**. When the length of muscle fibres remains the same and tension is increased, it is called **isometric** (same length) **contraction**.

Muscle Tonus (Muscle Tone). The state of sustained partial contraction is called muscle tonus or muscle tone.

Cori's Cycle. It was proposed by **Cori** and **Cori** who got Nobel Prize with **Houssay** in 1947. This cycle occurs in the muscles and liver. During glycolysis lactic acid is produced in the muscles. 1/5th of this lactic acid is oxidised to water and carbon dioxide and 4/5th lactic acid is converted into glycogen.

Oxygen Debt. During strenuous exercise, the muscle does not get sufficient oxygen to meet its energy needs immediately. So it contracts anaerobically and accumulates lactic acid produced by anaerobic glycolysis. During recovery, the oxygen consumption of muscle exceeds. The extra oxygen consumed during recovery is called oxygen debt of the muscle. It is used in oxidising the accumulated lactic acid aerobically and in restoring the depleted creatine phosphate and ATP in the muscle fibre. A small part of oxygen debt also goes to myoglobin which binds and stores oxygen for future use. For extra oxygen, deep and rapid breathing occurs carrying more oxygen into the lungs and eventually to the tissues.

Muscle Fatigue. The reduction in the force of contraction of a muscle after prolonged stimulation is called muscle fatigue. The accumulation of lactic acid leads to muscle fatigue. Pain is experienced in the fatigued muscle. The site of fatigue is the junction between nerve and muscle. Fatigued muscle needs extra oxygen to dispose off excess lactic acid. This results in the disappearance of fatigue.

Hypertrophy. Increase in the size of muscle cells is called **hypertrophy.** The increase is due to increase in the number of filaments in the sarcomeres in number of mitochondria and in the amount of sarcoplasm but it does not involve the division of muscle cells.

Atrophy. Reduction in the size of individual muscle cells is called atrophy. In atrophy the number

of filaments and mitochondria and the amount of sarcoplasmic reticulum are reduced. A lack of exercise or immobilization of muscles leads to atrophy.

Refractory Period. It is the interval during which a muscle fibre fails to respond to second stimulus. Refractory period is 0.002–0.005 sec. in a skeletal muscle fibre and 0.1–0.2 sec. in a cardiac muscle fibre.

Red and White Muscle Fibres

Birds and mammals have in their skeletal muscles two kinds of striated muscle fibres : red or slow muscle fibres and white or fast muscle fibres.

Red muscle fibres. These muscle fibres are dark red which is due to the presence of red haemoprotein called **myoglobin**. Myoglobin binds and stores oxygen as **oxymyoglobin** in the red fibres. Oxymyoglobin releases oxygen for utilization during muscle contraction. Red muscle fibres are rich in mitochondria. They carry out considerable aerobic oxidation. These muscle fibres have slow rate of contraction. Red muscle fibres perform sustained work at a slow rate but for a long time. Extensor muscles on the back of the human body are very rich in red muscle fibres. Some flight muscles of birds are red muscles.

White muscle fibres. They are much thicker. These muscle fibres are lighter in colour as they do not have myoglobin. Also poorer in mitochondria. They depend mainly on anaerobic oxidation (glycolysis) or energy production. These muscle fibres have a fast rate of contraction and are specialized for very fast and strenuous work for a short time only. Examples are muscles for eye ball movements ; flight muscles for short fast flying as in sparrow.

HUMAN SKELETAL SYSTEM

Hard external or internal structures of the animal body constitute the **skeleton**. The skeleton which is external is known as **exoskeleton**, *e.g.*, nails, hairs, etc. The **endoskeleton** consists of those hard parts which are present inside the body of the animal.

On the basis of the position of the skeletal structures in the body the endoskeleton is divisible into two parts.

1. **Axial skeleton.** It is present on the median longitudinal axis of the body. It consists of skull, vertebral column, sternum and ribs.

2. **Appendicular skeleton.** It is situated at the lateral sides which actually extend outwards from the principal axis. It consists of pectoral and pelvic girdles and bones of arms and legs.

Terms Related to Bones

Frontal— front,	Nasal— concerning nose,	Parietal bones— form roof and sides of the skull, Temporal— temple of forehead,
Occipital— back of skull,	Sphenoid— wedge-shaped,	Ethmoid—sieve-like,
Ear ossicles— ear bones,	Malleus— hammer,	Incus— anvil,
Stapes— stirrup,	Hyoid— concerning below,	Fossa— depression,
Foramen— aperture,	Zygomatic— cheek,	Maxilla— upper jaw,
Mandible— lower jaw,	Palatine— palate,	Lacrimal— tear,
Condyle—rounded structure,	Trochlea— pully like,	Crest— elevation,
Cervical— neck	Thoracic— chest	Lumbar— abdomen
Sacrum—inbetween the hips	Coccyx (caudal)— tail	Magnum— large
Xiphoid— like a sword	Patella— cap	Innominate— without name
Clavicle— collar	Sternum — concerning ventral side	Carpus— wrist
Fibula— concerning feeble	Pelvis— hip	Process— projection
Costal— pertaining to ribs		

The Skull

Skeleton of head is called skull. The skull consists of the following parts.

(i) Bones of the Cranium. The cranium is formed by 8 bones: 1 frontal bone, 2 parietal bones, 2 temporal bones, 1 occipital bone, 1 sphenoid bone and 1 ethmoid bone. Temporal bone has a projection called **mastoid.**

(ii) Ear ossicles. There are present 6 ear ossicles (2 malleus, 2 incus, and 2 stapes).

(iii) Hyoid bone. The hyoid bone is situated just above the larynx. Although it is not a bone of the skull proper, it is customarily considered with that portion of the skeleton.

(iv) Bones of the Face. There are 14 bones which form the skeleton of the face, 2 zygomatic bones, 2 maxilla, 2 nasal bones, 2 lacrimal bones, 1 vomer, 2 palatine bones, 2 inferior nasal conchae or turbinated bones and 1 mandible (dentary).

Thus the skull consists of 29 bones.

At the posterior end of the cranium there are two rounded protuberances, the **occipital condyles**, that articulate with the atlas (Ist vertebra).

Vertebral Column (Backbone)

The vertebral column is about 71 cm long. It is made up of 33 *vertebrae*. However, it consists of 26 bones because five sacral vertebrae are fused to form one sacrum and four coccygeal vertebrae are fused to form one coccyx. The components of the vertebral column are called **vertebrae** (sing. vertebra). A vertebra may have anterior processes called **prezgapophyses** and posterior processes termed as **postzgapophyses**. Prezygapophyses are directed upwards while postzygapophyses are directed downwards. These processes help articulation of the vertebrae with one another. The vertebrae are grouped into five groups.

(i) Cervical vertebrae— 7 in number, present in the neck, first cervical vertebra is called **atlas**, second cervical vertebra is known as **axis**. The axis has a peg like process called the **odontoid process.**

(ii) Thoracic vertebrae — 12 in number, present in the chest.

(iii) Lumbar vertebrae— 5 in number, present in the abdomen.

(iv) Sacrum. The five sacral vertebrae are fused in the adult, forming one structure called the **sacrum**, which lies between the innominate bones of the pelvic girdle.

(v) Coccyx. The four coccygeal vertebrae are fused to form a curved triangular bone, called the **coccyx**. It is a vestigial tail.

Vertebral Formula. The vertebral formula of human is $C_7T_{12}L_5S_{(5)}C_{(4)}$.

Curvatures (Bends). Human vertebral column shows four curvatures. (i) **Cervical curvature**— in the neck region, convex anteriorly. (ii) **Thoracic curvature**— in the thorax, concave anteriorly. (iii) **Lumbar curvature**— in the abdomen, convex anteriorly. (iv) **Sacral curvature**— in the pelvic region, concave anteriorly.

Human vertebrae are **acoelous (amphiplatyan)**. *i.e.*, centrum is without concavity.

Sternum or Breast Bone

It is about 15 cm long and consists of three parts— the **manubrium** is the uppermost part, the **body** is the middle portion and the **xiphoid process** is the tip of the bone. The true ribs (7 pairs) are attached to the sternum.

Ribs

There are 12 pairs of ribs which form the bony lateral walls of the thoracic cage.

1. The first seven pairs are called **true ribs** because their anterior ends are attached directly to the sternum by means of small pieces of hyaline cartilage, the **costal cartilages**.

2. The eighth, ninth and tenth pairs of the ribs are called **false ribs**. They articulate by cartilage with costal cartilage of the seventh rib and thus are attached indirectly to the sternum.

3. The last two pairs of ribs are called **floating ribs** because their anterior ends are not attached to either the sternum or the cartilage of another rib. The floating ribs protect the kidneys.

A typical (generalized) rib consists of two parts: **vertebral part** and **sternal part.** The vertebral part is long and bony and articulates with the thoracic vertebrae by facets. The sternal part is short and cartilaginous which articulates with sternum or sternal part of it's upper rib.

Pectoral (Shoulder) Girdles

Each pectoral girdle consists of 1 clavicle and 1 scapula. At the point where the superior and lateral borders of the scapula meet there is the lateral angle which presents a shallow articular surface termed the **glenoid cavity** into which the head of the humerus is articulated. Each pectoral girdle has expanded process called **acromion**.

Bones of the Arms

Each arm consists of 1 humerus with deltoid ridge, 1 radius, 1 ulna, 8 carpal bones, 5 metacarpal bones, 5 digits (14 phalanges). Phalangeal formula: 2, 3, 3, 3, 3. Thus each arm consists of 30 bones.

Pelvic Girdle

The pelvis or pelvic girdle is formed by two **innominate bones** (hip bones). The sacrum and coccyx also take part in the formation of the pelvis. Each innominate bone consists of three separate bones, the **ilium,** the **ischium** and the **pubis.** On its outer surface it has a deep depression called the **acetabulum.** The head of the femur fits into the actetabulum and forms hip joint. The ilium has one large depression, the **greater sciatic notch** through which the **sciatic nerve**, the longest nerve, passes. The ischium also has one small depression the **lesser sciatic notch**. There is also present an **obturator foramen** occupied by a membrane. **Pubic symphysis** is made up of white fibrous cartilage.

Bones of the Legs

The bones which make up the leg are— 1 femur with trochanters, 1 tibia, 1 fibula, 1 patella (knee cap), 7 tarsal bones, 5 metatarsal bones, 5 digits (14 phalanges). Phalangeal formula : 2, 3, 3, 3, 3. Thus each leg consists of 30 bones.

Total number of Bones in Human Body

I. Axial Skeleton		**Number of bones**
A. Skull :	Cranium	8
	Face	14
B. Hyoid (Above the larynx)		1
C. Ear ossicles (ear bones), 3 in each ear		6
D. Vertebral column		26
E. Thorax :	Sternum	1
	Ribs	24
		80
II. Appendicular skeleton		
A. Shoulder girdles (Pectoral girdles)		
	Clavicle	2
	Scapula	2

B. Upper Extremities (Arms)

Humerus	2
Ulna	2
Radius	2
Carpals	16
Metacarpals	10
Phalanges	28

C. Pelvic Girdle

Innominate	2

D. Lower extremities (Legs)

Femur	2
Fibula	2
Tibia	2
Patella	2
Tarsals	14
Metatarsals	10
Phalanges	28
	126

Total bones in human body = 80 + 126 = 206

Comparison Between Female and Male Skeleton

1. **Skull.** The female skull is lighter in weight.
2. **Shoulders.** They are relatively narrow in females and are broad in males.
3. **Sacrum.** The female sacrum is shorter and wider.
4. **Pelvis.** The female pelvis is lighter and broader.
5. **Pelvic Cavity.** The female pelvic cavity is wider in diameter because it has to accommodate the growing foetus during pregnancy.
6. **Coccyx.** The female coccyx is more movable than the male coccyx.

Types of Bones

(A) According to the shape and size, bones are classified into four categories.

(i) **Long bones**, *e.g.*, humerus of upper arm, radius and ulna of forearm, femur of thigh and tibia and fibula of shank.

(ii) **Short bones**, *e.g.*, metacarpals of palm, metatarsals of sole, phalanges of fingers and toes.

(iii) **Flat bones**, *e.g.*, scapula of pectoral girdle, sternum and cranial bones.

(iv) **Irregular bones**, *e.g.*, vertebrae, carpals of wrist and tarsals of ankle.

(B) On the basis of its texture, a bone is of two types

(i) **Compact Bone (Dense bone).** It is present in the shaft (diaphysis) of long bones. Haversian system is present. It contains yellow bone marrow. It stores fat and produces blood corpuscles in emergency.

(ii) **Spongy Bone.** It is present in vertebrae, ribs, skull bones and epiphyses (expanded ends) of long bones. Haversian system is absent. It contains red bone marrow. It produces RBCs and granular leucocytes.

(C) Types of bones according to their source of formation

(i) Cartilaginous or Replacing Bones. They replace the cartilage. Examples : humerus, femur.

(ii) Investing or Dermal or Membrane Bones. These bones develop in the dermis of the skin. Examples : frontal, nasals, vomer and parietals of the skull.

(iii) Visceral Bones. These are formed in the soft organs (viscera). Examples : **os cordis** in the heart of deer, **os penis** in the penis of most bats, insectivores rodents (rats), carnivores (*e.g.*, dog, walrus) and **os palpebrae** in the eye lids of crocodiles. A small bone also develops in the crest of a bird and snout of a hog.

(iv) Sesamoid Bones. These bones are formed in the tendons at the joints. Example : patella (knee cap), fabellae bones and pisciform (a carpal). Fabella is a small sesamoid bone in the tendon of the lateral head of the gastrocnemius muscle.

JOINTS

1. Fibrous or immovable joints. There is **white fibrous tissue** between the ends of the bones. Examples of this type include the joints between the bones of skull called **sutures** and the joints between the teeth and the maxilla and teeth and mandible.

2. Cartilaginous or slightly movable joints. In this type there is a pad of **white fibrocartilage** between the ends of the bones taking part in the joints which allows for very slight movement. Movement is only possible because of compression of pad of cartilages. Examples of cartilaginous joints include the pubic symphysis of pubis and the joints between the vertebrae (intervertebral discs).

3. Synovial or freely movable joints. There is present a membrane called **synovial membrane.** This membrane is composed of secretory epithelial cells which secrete a thick sticky fluid, of the consistency of the white of an egg called **synovial fluid.** It acts as a lubricant to the joint, provides nutrient materials for the structures within the joint cavity and helps to maintain the stability of the joint. It prevents the ends of the bones from being separated. Bone ends are covered by **articular cartilages. Ligaments** join the bones and **tendons** connect the bones with muscles. Little sacs of synovial fluid or **bursae** are found in some joints. Their position is such that they act as cushions to prevent friction between a bone and a ligament or tendon, or the skin.

If the bone can move in only one plane, the joint is called **monaxial**, if it can move in two planes it is **biaxial** if the joint can move in several planes, it is called **multiaxial** and if the motion they allow does not occur around the axis, the joint is termed as **nonaxial.**

Types of Synovial Joints. According to their shapes and the movements they allow, the synovial joints are of six types:

(i) Gliding (Planer) joints are found between the carpal bones, between the tarsal bones, between zygapophyses of adjacent vertebrae. The joint is **nonaxial.**

(ii) Hinge joint. The elbow, the knee, ankle, interphalangeal and between humerus and ulna are examples of hinge joints. The joint is **monaxial.**

(iii) Pivot joint. The joints between the atlas and axis and between the radius and ulna just below the elbow are examples of pivot joints. The joint is **monaxial.**

(iv) Ellipsoid or condyloid joint. The joints between the metacarpals and phalanges of the fingers are examples of ellipsoid joints. This joint is **biaxial.**

(v) Saddle joint. An example of a saddle joint is the carpometacarpal joint between the trapezium (a carpal) and metacarpal of the thumb. The join is **biaxial.**

(vi) Ball-and-socket joint. Shoulder and hip joints are the examples of ball and socket joint. At the shoulder joint, the head of the humerus fits into the glenoid cavity of the pectoral girdle. At the hip joint, the head of the femur fits into the acetabulum of pelvic girdle. The joint is **multiaxial.**

ROLE OF MUSCLES AND BONES IN MOVEMENT– (LEVER SYSTEMS)

The bones and joints, function as lever. A lever has three basic parts : the **fulcrum** (F)– fixed point, the **point of effort (E)** and the **resistance (R)** or load. The fulcrum is the point about which the lever moves. In the body fulcrum is always a joint. The point of effort is the attachement of a muscle to bone; it is where the force is exerted. The resistance (load) is the force to be overcome or the weight to be lifted.

Levers are categorized into **three types** according to the positions of the fulcrum, the effort and the resistance.

1. **First-class Lever.** In a first calss lever, the fulcrum is placed between the effort and the resistance. An example of a first class lever is a se-saw (long board supported in middle so that ends on which children, etc. sit move aternately up and down). There are not many first class levers in the body. One example is the head resting on the vertebral column.

2. **Second-class Lever** In a second class lever the resistance is between the fulcrum and the effort. This lever operates like a wheel barrow (shallow open box with shafts and open wheel for carrying small loads on). There are very few examples of second-class levers in the body. One example is raising the body on the toes.

3. **Third-class Lever.** In third-class lever the effort is between the fulcrum and the resistance. They are the most common levers in the body. An example is flexing the forearm at the elbow.

DISORDERS OF MUSCULAR AND SKELETAL SYSTEM

1. **Arthritis.** It is caused by the inflammation of the joints. Arthritis is of several types, three types of arthritis are described here.

(i) **Rheumatoid arthritis (RA)** is most common arthritis. It is diagnosed by the presence of rheumatoid factor (a type of immunoglobulin IgM). Rheumatoid arthritis is an inflammation of the synovial membrane in synovial joints. When this membrane, which is source of synovial fluid, becomes inflamed, it produces too much fluid. In fact the synovial membrane starts secreting abnormal granules called **pannus**, which after accumulating on the surface of the articular cartilage, cause its erosion. The fibrous tissues are attached with the bones, making the joints immovable. The joints swell and become extremely painful. Pain and inflammation can be reduced by heat treatment and physiotherapy. In extreme cases, replacement of the damaged joints is done.

(ii) **Osteoarthritis (OA)** affects the articular cartilage at the synovial joints. The cartilage erodes and due to proliferation new bone is deposited. It is a degenerative joint disease. Usually, affected joints are of spine, knees and hands. It is the most common type of joint disease.

Gouty Arthritis. It is inflammation of joints due to accumulation of uric acid crystals in the joints.

2. **Osteoporosis.** Osteoporosis is a disease in which bone loses minerals and fibres from its matrix. Individuals who are under prolonged treatment of cortisone, are prone to bone loss, leading to osteoporosis. Major causative factors of osteoporosis are imbalances of hormones like calcitonin of thyroid, parathormone of parathyoid and deficiencies of calcium and vitamin D and sex hormones. Decreased levels of oestrogen (a female sex hormone) is a common cause.

3. **Rickets and Osteomalacia.** In children rickets occurs and it is called osteomalacia in adults. In these diseases the bones contain insufficient amount of calcium.

4. **Sprain.** A sprain is a twisting of a joint without dislocating it. Such an injury causes damage to ligaments and also often damages tendons, muscles, blood vessels, and nerves. Severe sprains are quite painful and require immobilization during the healing process.

5. **Slipped Disc.** It is a displacement of vertebrae and intervertebral fibrocartilage disc from their normal position.

Muscular dystrophy. It involves degeneration of skeletal muscles due to genetic defect.

Myasthenia gravis. It is an *autoimmune disorder* that affects neuromuscular junction causing fatigue, weakening and paralysis of skeletal muscle.

Paget's disease. This disease is caused by abnormal bone resorption by abnormal osteoclasts.

Tetany. It is a muscular disorder in which rapid spasms in muscle occur due to lesser calcium in the body fluid.

READ AND DIGEST

- Most mammals have 7 cervical vertebrae. Exceptions (i) 2 – toed sloth (Choloepus)— 6 cervical vertebrae. (ii) 3–toed sloth (Bradypus)— 9 cervical vertebrae. (iii) Antbear (Tamandua)— 8 cervical vertebrae. (iv) Manatee (Trichochus)— 6 cervical vertebrae.
- **Where is your funny bone** ? Some people think your funny bone is so called because when you knock a particular part of your elbow, you get funny, tingling sensation. The real reason is because the medical name is the humerus and since it is pronounced 'humorous', the description of 'funny bone' has now passed into universal use.
- **Types of Vertebrae.** On the basis of the shape of the centra, vertebrae are of the following types :

  (i) **Procoelous.** Centrum is concave anteriorly and convex posterioly *e.g.,* typical vertebrae of frog lizard, snakes and some crocodilian. (ii) **Opisthocoelous.** Posterior face of centrum is concave and anterior face is convex, *e.g,* vertebrae of tailed amphibians (*e.g.,* Salamanders). (iii) **Amphicoelous.** Centrum is concave at both ends *e.g.,* vertebrae of most fishes, 8th vertebra of frog. *Sphonodon* and some crocodilians. (iv) **Acoelous or Amphiplatyan.** Centrum is flat at both ends, without a concavity, *e.g.,* 9th vertebra of frog, vetebrae of most mammals. (v) **Heterocoelous.** Centrum is like saddle *e.g.,* vertebrae of birds.
- **Jaw Suspensions.** There are 5 main types of jaw suspensions (methods of attachment).

  (i) **Autodiastylic,** *e.g.,* earliest gnathostomes such as acanthodians. (ii) **Amphistylic.** This is a rather primitive arrangement found in crossopterygii and some primitive sharks (*e.g., Heptanchus, Hexanchus*). (iii) **Hyostylic,** *e.g.,* elasmobranchs and bony fishes. (iv) **Autostylic,** *e.g.,* placoderms, chimaeras, lung fishes and most amphibians, reptiles and birds. (v) **Craniostylic,** *e.g.,* mammals. It is considered as a modification of autostylic suspension.
- **Smallest bone**— Stapes.
- **Longest bone**— Femur.
- **Largest foramen**— Foramen magnum in the skull. The spinal cord begins at the foramen magnum.
- **Largest muscle**— *Gluteus maximus* (buttock muscle).
- **Biggest muscle**— *Quadriceps femoris* (thigh muscle).
- **Strongest muscle**— Masseters of the lower jaw.
- **Smallest muscle**— Stapedius which controls the stapes.
- **Myalgia**— pain in muscle.
- Total number of muscles in human body is 639.
- **Kinesiology**— The scientific study of body movements is called kinesiology.
- **Occipital condyles** (i) **Monocondylic**— skulls of reptiles and birds; (ii) **Dicondylic**— skulls of frog and man.
- Tenth rib is also usually "floating" in **Japanese**. This condition is also recorded in other races.
- Weberian ossicles are modified vertebrae and are found in carps and cat fishes. They connect the air bladder with the internal ear.
- Jet propulsion mode of locomotion is characteristic of cephalopods (molluscs).
- Calcium and magnesium ions are required during muscular contraction.
- Glycogen can be formed more readily from glucose in muscles,

- Animals with ``**liquid skeleton** -- Earthworms, Caterpillars (larvae of butter flies and silk moths), and slugs. It gives shape and support to the body.
- Arthology — Study of joints
- Osteology — Study of bones.
- Craniology — Study of skull.
- Myology— Study of muscles.
- Flexation of thigh, knee and their rotation is facilitated by **sartorius muscle.**
- Strongest bone— Tibia (Shin bone)
- Largest Synovial joint— Knee joint.

MULTIPLE CHOICE QUESTIONS

1. Striped muscle are
(1) syncytial (2) uninucleate
(3) spindle shaped (4) none of these

2. Functional unit of skeletal muscle is called
(1) Sarcolemma (2) Z-band
(3) Sarcomere (4) Sarcoplasm

3. Sarcomere is the part between two
(1) H-lines (2) A-lines
(3) I-bands (4) Z-lines

4. Statements
A. A-bands of the muscle are dark and contain myosin
B. I-bands are the light bands and contain actin
C. During muscle contraction the A-band contracts
D. The part between the two Z-lines is called as sarcomere
E. The central part of thin filament, not overlapped by thick filament is called H-zone

Of the above statements.
(1) A, C, E are correct while B, D are incorrect
(2) A, B, C and E are correct while D is incorrect
(3) A, B and D are correct while C and E are incorrect
(4) A, B and C are correct while D and E are incorrect

5. H-zones are found in
(1) myofibril of unstriated muscle
(2) myofibril of striated muscle
(3) light band
(4) none of the above

6. Major protein in the thick filaments of skeletal muscle fibre is
(1) actin (2) myosin
(3) troponin (4) tropomyosin

7. Myosin myofilaments are
(1) attached to the Z-disk
(2) absent from the H-zone
(3) found primarily in the I-band
(4) none of the above

8. The largest muscle in the human body is
(1) gluteus maximus
(2) stapedius
(3) sartorius
(4) masseter

9. Smallest muscle in the human body is
(1) stapes (2) sartorius
(3) stapedius (4) spinal muscle

10. Quadriceps and gastrocnemius muscles lie in
(1) lower limb (2) hands
(3) wrist (4) shoulder

11. Smooth muscles are
(1) involuntary, spindle shaped, uninucleated, unbranched
(2) voluntary, multinucleate and cylindrical
(3) involuntary, cylindrical, multinucleate
(4) voluntary, branched, uninuclear

12. Largest smooth muscle is present in
(1) leg (2) thigh
(3) heart
(4) uterus of pregnant woman

13. Striated muscles contract because of
(1) sliding of myosin filaments on actin filaments
(2) sliding of actin filaments on myosin filaments
(3) myosin filaments coming close to each other
(4) actin filaments sliding over one another

14. During muscle contraction
(1) size of I-band increases
(2) diameter of fibre increases
(3) size of A-bands remains same
(4) size of H-zone becomes larger

15. When a skeletal muscle shortens during contraction, which of these statements is false?
(1) The I-bands shorten
(2) The A-bands shorten
(3) The H-bands shorten
(4) The sarcomeres shorten

16. Which statement is correct for muscle contraction?
(1) Length of H-zone decreases
(2) Length of A-band decreases

(3) Length of two Z-line increases
(4) Length of I-band remains constant

17. During contraction of skeletal muscle Ca^{2+} bind to
(1) actin (2) troponin
(3) tropomyosin (4) myosin ATPase

18. The long protein molecule, which masks the active sites on the F-actin is
(1) myosin (2) troponin
(3) tropomyosin (4) light meromyosin

19. Which of these statements about the molecular structure of myofilaments is true?
(1) ATPase is found on troponin
(2) Tropomyosin has a binding site for Ca^{2+}
(3) Troponin binds to the rodlike portion of myosin
(4) The head of the myosin molecule binds to an active site on actin

20. Which yield ATP during muscle contraction?
(1) Oxygen (2) Myoglobin
(3) Cholesterol
(4) Creatine phosphate

21. The lactic acid generated during muscle contraction is converted to glycogen mainly in
(1) liver (2) muscle
(3) adrenals (4) pancreas

22. During fatigue
(1) muscle fails to relax
(2) muscle fails to be stimulated
(3) blood circulation in muscles stops
(4) motor nerve does not respond to external stimulus

23. Stimulus several times greater than threshold stimulus is provided to muscle fibre. It will
(1) undergo tetany
(2) contract slightly
(3) contract forcefully
(4) contract with same force

24. Muscle activity of our body
(1) decreases BMR
(2) decreases venous return
(3) increases body temperature
(4) reduces blood and lymph flow

25. The muscles which contract to produce opposite movements at the same joint are called
(1) synergists (2) antagonists
(3) prime movers (4) none of these

26. Which of the following are not antagonistic muscles?
(1) Flexor and extensor
(2) Pronator and supinator
(3) Abductor and adductor
(4) Protractor and supinator

27. Biceps and triceps surround
(1) ulna (2) femur
(3) radius (4) humerus

28. The muscle which on contraction rotates the forearm to make palm face upward and forward is
(1) pronator (2) supinator
(3) abductor (4) adductor

29. When body part moves towards the median axis, it is called
(1) adductor (2) pronator
(3) abductor (4) supinator

30. For the elbow joint, triceps is
(1) flexor (2) extensor
(3) adductor (4) retractor

31. Spreading the fingers apart is
(1) rotation (2) flexion
(3) abduction (4) depression

32. Red muscle fibres are rich in
(1) cholesterol (2) lysosomes
(3) microsomes (4) mitochondria

33. Which of the following statements is not true?
(1) White muscle fibres are rich in mitochondria
(2) Muscles of eyeball movements are white fibres
(3) Red muscle fibres are slower in contraction rate
(4) White muscle fibres depend mainly on anaerobic glycolysis

34. Red muscles are rich in
(1) relaxin (2) myosin
(3) lactic acid and acetic acid
(4) myoglobin and cytochrome

35. A single isolated contraction of the muscle fibre is called
(1) twitch (2) fatigue
(3) tetanus (4) contracture

36. A sustained state of contraction caused by rapid succession of many stimuli is
(1) twitch (2) fatigue
(3) tetanus (4) contracture

37. Which of the following is a short bone?
(1) Carpal (2) Patella
(3) Sternum (4) Humerus

38. Which of the following is a flat bone?
(1) Tibia (2) Tarsal
(3) Malleus (4) Sternum

39. The smallest irregular bone in man is
(1) nasal (2) stapes
(3) patella (4) palatine

40. Long bones of mammals provide
(1) support only
(2) support and produce RBCs only
(3) support and produce WBCs only
(4) support and produce RBCs and WBCs

41. Ends of the long bones are covered by
(1) tendons (2) cartilage
(3) ligaments (4) blood cells

42. Bone formed by the ossification of a tendon is called
(1) dermal bone (2) cartilage bone
(3) sesamoid bone (4) membrane bone

43. Which one is formed by the ossification of tendon?
(1) Tibia (2) Patella
(3) Trapezoid (4) Calcaneum

44. Total number of bones in the adult human is
(1) 206 (2) 406
(3) 106 (4) 306

45. Which of these is a part of appendicular skeleton?
(1) Ribs (2) Cranium
(3) Clavicle (4) Vertebrae

46. Number of bones in human appendicular skeleton is
(1) 80 (2) 126 (3) 120 (4) 142

47. Find out the correct order of number of bones in the parts of skull such as cranial bone, facial bone, hyoid bone and middle ear bones respectively
(1) 14, 8, 1 and 3 (2) 3, 8, 14 and 1
(3) 8, 14, 1 and 3 (4) 14, 8, 3 and 1

48. Cheek bones are
(1) parietals (2) ethmoids
(3) lacrimals (4) zygomatic

49. Foramen magnum is present at
(1) base of skull
(2) base of brain
(3) base of medulla
(4) apex of vertebral column

50. The only movable bone in the skull is
(1) mandible (2) maxilla
(3) ethmoid (4) none of these

51. Lower jaw of man is made up of
(1) 1 bone (2) 2 bones
(3) 3 bones
(4) no bones, only muscles

52. Hyoid bone is located at the
(1) front of the skull
(2) behind the skull
(3) top of the buccal cavity
(4) floor of the buccal cavity

53. The number of vertebrae present in cervical, thoracic, lumbar, sacral and coccyx regions are respectively
(1) 7, 12, 5, 1, 1 (2) 7, 5, 1, 12, 1
(3) 12, 7, 5, 1, 1 (4) 1, 7, 5, 12, 1

54. Consider the following statements
A. In man, vertebral column has 33 vertebrae organized as 28 bones.
B. Pelvic girdle is made up of two fused bones only.
C. Osteoporosis is characterized by microarchitectural deterioration of the bone.
(1) A alone is correct
(2) B alone is correct
(3) C alone is correct
(4) A alone is incorrect

55. In man, coccygeal bone is formed by the fusion of .... vertebrae.
(1) 3 (2) 4 (3) 5 (4) 6

56. Which of the following form thoracic cage of man?
(1) Ribs and sternum
(2) Ribs and thoracic vertebrae
(3) Ribs, sternum and lumber vertebrae
(4) Ribs, sternum and thoracic vertebrae

57. Manubrium is a part of
(1) Skull (2) Pelvic girdle
(3) Thoracic cage (4) Pectoral girdle

58. Ribs attached to sternum are
(1) first seven pairs
(2) all ten ribs
(3) first ten rib pairs
(4) first five rib pairs

59. Floating ribs of thoracic cage are
(1) 1st to 7th pair (2) 8th to 9th pair
(3) 8th to 10th pair (4) 11th to 12th pair

60. Which of these statements concerning ribs is true?
(1) There are five pairs of floating ribs
(2) Floating ribs do not attach to vertebrae
(3) The head of the rib attaches to the manubrium of sternum
(4) The true ribs attach directly to the sternum with costal cartilage

61. Which one is a part of pectoral girdle?
(1) Ilium (2) Ischium
(3) Acetabulum (4) Glenoid cavity

62. 'Collar bone' is
(1) patella (2) scapula
(3) clavicle (4) coracoid

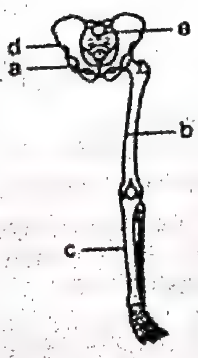
63. The point where the scapula and clavicle articulate is
(1) glenoid cavity (2) coracoid process
(3) trochlea (4) acromion process

64. When comparing the pectoral girdle with the pelvic girdle which of these statements is true?
(1) The pelvic girdle is more firmly attached to the body than the pectoral girdle
(2) The pectoral girdle has the limbs more securely attached than the pelvic girdle
(3) The pelvic girdle allows greater mobility than the pectoral girdle
(4) The pectoral girdle has greater mass than the pelvic girdle

65. How many bones are present in our arms?
(1) 32 (2) 60 (3) 45 (4) 25

66. Number of wrist bones is
(1) 8 (2) 9 (3) 7 (4) 6

67. Consider the diagram given below



Parts labelled as (a), (b), (c), (d) and (e) respectively indicate
(1) Ilium, femur, tibia, pubis and sacrum
(2) Pubis, femur, tibia, ilium and sacrum
(3) Pubis, tibia, femur, ilium and sacrum
(4) Pubis, femur, ilium tibia, and sacrum

68. The total number of bones in the hindlimb of a man is
(1) 14 (2) 21 (3) 24 (4) 30

69. The bone of the foot to which the tibia is attached is
(1) talus (2) metatarsals
(3) phalanges (4) calcaneus

70. Digital formula of both limbs in man is
(1) 2, 3, 3, 4, 3 (2) 2, 3, 3, 3, 3
(3) 3, 3, 3, 3, 2 (4) 2, 2, 3, 3, 3

71. Immovable joint is
(1) synarthrodial (2) amphiarthrodial
(3) diarthrodial (4) all of these

72. The type of joint between the human skull bones is
(1) hinge (2) fibrous
(3) synovial (4) cartilaginous

73. Sutural joints are found between
(1) parietals of skull
(2) thumb and metatarsal
(3) humerus and radio-ulna
(4) glenoid cavity and pectoral girdle

74. Which of the following is a cartilaginous joint?
(1) Suture (2) Elbow joint
(3) Synovial joint (4) Pubic symphysis

75. The joint where synovial cavity is absent
(1) carpals
(2) finger and toes in males
(3) pubic symphysis in females
(4) femur and pelvis in females

76. What is the joint between sternum and ribs in humans?
(1) Fibrous joint (2) Gliding joint
(3) Angular joint (4) Cartilaginous joint

77. Articular cartilage of synovial joint is
(1) fibrocartilage (2) elastic cartilage
(3) hyaline cartilage (4) all of these

78. Synovial joint occurs between
(1) pubic bones
(2) centra of two vertebrae

(3) two skull bones
(4) humerus and ulna

79. In locomotion, movement between two structures of which one of the following sets takes part in man?
(1) Skull and atlas
(2) Humerus and ulna
(3) Femur and pelvic girdle
(4) Humerus and pectoral girdle

80. The joint between incus and stapes is
(1) hinge joint (2) gliding joint
(3) pivotal joint
(4) ball and socket joint

81. Hinge joint is present in our body between
(1) thumb and trapezium
(2) humerus and scapula
(3) humerus and radio-ulna
(4) first and second vertebra

82. Saddle joint occurs between
(1) carpal and first metacarpal
(2) femur and pelvic girdle
(3) all the vertebrae
(4) phalanges

83. The articulation of odontoid process of axis and atlas is an example of
(1) pivot joint (2) synovial joint
(3) ball and socket joint
(4) none of these

84. Which of these joints is correctly matched with the type of joint?
(1) Atlas to occipital condyle – Pivot
(2) Tarsals to metatarsals – Saddle
(3) Tibia to talus – Hinge
(4) Femur to coxal bone – Ellipsoid

85. An example of gliding joint is
(1) femur and tibiofibula
(2) humerus and glenoid cavity
(3) zygapophyses of adjacent vertebrae
(4) occipital condyle and atlas

86. Which of the following permits movement of articulating bones around two axes?
(1) Hinge joint (2) Ball & socket joint
(3) Sutures (4) Ellipsoid joint

87. In old age, stiffness of joints is due to the
(1) higher viscosity of synovial fluid
(2) decrease in synovial fluid
(3) increase in synovial fluid
(4) none of above

88. Gout is a disease that affects the joints and leads to arthritis. It is associated with an abnormality of
(1) fat metabolism
(2) purine metabolism
(3) protein metabolism
(4) pyrimidine metabolism

*89. Study the following
A. The accumulation of pyruvic acid in the muscle causes fatigue
B. ATP is resynthesized in the muscle by the phosphorylation of ADP by a phosphagen.
C. Cori and Cori cycle occurs in the liver
D. The phosphagen in the vertebrate muscle is arginine phosphate.

The correct set of answers for muscle contraction is
(1) A and D (2) B and D
(3) C and D (4) B and C

90. In the pelvic girdle of man A, B, C, D and E respectively represent

(1) A = Pubis, B = Acetabulum, C = Ilium, D = Ischium, E = Pubic symphysis
(2) A = Ilium, B = Acetabulum, C = Pubis, D = Ischium, E = Pubic symphysis
(3) A = Ischium , B = Acetabulum, C = Pubis, D = Ilium, E = Pubic symphysis
(4) A = Ilium, B = Pubis, C = Acetabulum, D = Pubic symphysis, E = Ischium

91. It is an outcome of irregularities in metabolism of nitrogenous waste
(1) Osteoporosis (2) Osteoarthritis
(3) Gouty arthritis
(4) Rheumatoid arthritis

92. Upon stimulation of skeletal muscles calcium is immediately made available for binding to troponin from

*89. Muscle fatigue is caused by lactic acid. The phosphagen or the source of energy in muscles is phosphocreatine.

(1) bone (2) blood
(3) lymph
(4) sarcoplasmic reticulum

93. This facial bone is unpaired
(1) vomer (2) nasal
(3) lacrimal (4) palatine

94. The longest bone of the human body is
(1) tibia (2) incus
(3) femur (4) vertebra
(Kerala PMT 2009)

95. Skeletal muscles are controlled by
(1) autonomic nerves
(2) somatic nerves
(3) sympathetic nerves
(4) parasympathetic nerves

96. Which one of the following is wrongly matched?
(1) Red muscle - Myoglobin
(2) Troponin - Protein of myosin filament
(3) Tendon - Connective tissue
(4) Myosin - Contractile protein
(5) Smooth muscle - Involuntary muscle

97. The generation of excitation-contraction coupling involves all the following events except
(1) hydrolysis of ATP to ADP
(2) confirmational change in troponin
(3) release of calcium from troponin
(4) formation of cross-linkages between actin and myosin

98. In human beings, the cranium is formed by
(1) ten bones of which two are paired
(2) eight bones of which two are paired
(3) fourteen bones of which six are paired
(4) eight bones of which three are paired

99. The number of occipital condyles in man is
(1) one (2) two (3) three (4) four
(Kerala PMT 2010)

100. Match the following and choose the correct option

Types of synovial joints	Bones involved
A Ball and socket	1. Carpal and metacarpal of thumb
B Hinge	2. Atlas and axis
C Pivot	3. Frontal & parietal
D Saddle	4. Knee
	5. Humerus and pectoral girdle

Answer codes :
(1) A = 1, B = 3, C = 4, D = 5
(2) A = 5, B = 4, C = 2, D = 1
(3) A = 5, B = 4, C = 3, D = 1
(4) A = 1, B = 2, C = 5, D = 4
(Kerala PMT 2010)

101. The ellipsoidal joint is found in
(1) hip (2) knee
(3) shoulder
(4) radius and scaphoid of hand

102. Which of the statements about the mechanism of muscle contraction are correct?
I. Acetylcholine is released when the neural signal reaches the motor end plate.
II. Muscle contraction is initiated by a signal sent by CNS *via* a sensory neuron.
III. During muscle contraction, isotropic band gets elongated.
IV. Repeated activation of the muscles can lead to lactic acid accumulation.
(1) I and IV alone are correct
(2) I and III alone are correct
(3) II and III alone are correct
(4) I, II and III alone are correct
(Kerala PMT 2011)

103. Actin binding sites are located on
(1) troponin (2) tropomyosin
(3) meromyosin
(4) both troponin and tropomyosin
(Kerala PMT 2011)

104. Scapula is a large triangular flat bone situated in the dorsal part of the thorax between the
(1) second and fifth ribs
(2) third and sixth ribs
(3) third and eighth ribs
(4) second and seventh ribs
(Kerala PMT 2011)

105. The coxal of the pelvic girdle is formed by the fusion of
(1) ilium and scapula
(2) clavicle and pubis
(3) scapula and clavicle
(4) ilium, ischium and pubis
(Kerala PMT 2011)

106. Which one of the following pairs of substances and function is not correctly matched?
(1) Actin : Slides past myosin causing contraction

(2) Calcium : Triggers enzymatic action of Myosin
(3) ATPase : Enzyme that splits ATP
(4) ATP : Supplies energy for breaking Actomyosin

*107. Read the following statements
(i) In cardiac muscle fibres sarcoplasmic reticulum is poorly formed
(ii) Blood supply is scanty in case of smooth muscle fibres
(iii) Tropomyosin occurs in actin filaments in the form of complexes which are arranged over actin fibres and represent sites where myosin binds to actin.
(iv) Salts of citrate and oxalates act as anticoagulants as they precipitate Ca^{2+}.

Select the correct statements
(1) (i), (ii), (iii) (2) (i), (iii), (iv)
(3) (ii), (iii), (iv) (4) (i), (ii), (iv)

*108. Select the wrong match
(1) Rings of trachea and bronchi - Hyaline cartilage
(2) Nasal septum - Elastic cartilage
(3) Pubic symphysis - White fibrous cartilage
(4) Eustachian tube - Elastic cartilage

109. Read the following statements
(i) In adults most of the RBCs are produced in the marrow of long bones.
(ii) In camel and Llama RBCs are oval.
(iii) Foetal RBCs are nucleated and contain a different form of haemoglobin as compared to the adults.
(iv) Lymphocytes are 60 – 70% of the total leucocytic count.

Select the correct statements
(1) (i), (ii) and (iii) (2) (i) and (ii)
(3) (ii) and (iii) (4) (ii), (iii) and (iv)

*110. Go through the following statements
(i) During muscle contraction, the width of A-band remains constant while I-band shortens.
(ii) During muscle contraction, the Ca^{2+} released from the SR bind to the troponin component of thin filament
(iii) The process of muscle contraction is faster in smooth muscle as they have a well developed sarcoplasmic reticulum.
(iv) The red muscle fibres have abundant mitochondria, low glycogen and poorly formed sarcoplasmic reticulum.

Which of these are correct?
(1) (i), (ii) and (iii) (2) (i), (ii) and (iv)
(3) (i), (iii) and (iv) (4) All are correct

*111. Go through the following matches
(i) Gluteal tuberosity - Tibia
(ii) Medial malleolus - Fibula
(iii) Greater trochanter - Femur

Which of these are correct?
(1) (ii) only (2) (iii) only
(3) (i) and (ii) (4) (ii) and (iii)

*112. Go through the following matches
(i) Pisiform - Bone in distal row of wrist
(ii) Lateral and medial condyles - Femur
(iii) Ethmoid - Pneumatic bone

Which of these are correct?
(1) (i) and (ii) (2) (ii) and (iii)
(3) Only (iii) (4) All are correct

*113. Go through the following statements
(i) Thoracic vertebrae have got foramina transversaria in their transverse processes.
(ii) Atlas permits up and down or nodding movement of skull on it.
(iii) The body of human vertebra is amphiplatyan in nature.
(iv) Without exception, all mammals have seven cervical vertebrae

Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii) and (iii)
(3) (ii), (iii) & (iv) (4) (i), (iii) & (iv)

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*107. Troponin covers the active sites and not tropomyosin. Tropomyosin occurs in the form of a long fibre.
*108. Nasal septum is hyaline cartilage.
*110. The process of muscle contraction is slower in smooth muscle as they have a poor formed SR.
*111. Gluteal tuberosity is part of femur and medial malleolus is part of tibia.
*112. Pisiform is in the proximal row of the wrist.
*113. Foramina transversaria are present in cervical vertebrae. Some mammals not having 7 cervical vertebrae are 2-toed sloth (6), 3-toed sloth (9), Ant bear (8).

*114. Go through the following matches
(i) Wrist joint - Angular joint
(ii) Interphalangeal joint - Angular Joint
(iii) Metacarpophalangeal joint - Hinge joint
(iv) Carpal bones - Gliding joint
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) and (iv)
(3) (i) and (iv) (4) (i), (iii) and (iv)

*115. Select the wrong match
(1) Epiphyseal plate of long bones - Hyaline cartilage
(2) Intervertebral disc - White fibrous cartilage
(3) Pinna - Elastic cartilage
(4) Xiphisternum - Elastic cartilage

*116. Read the following statements
(i) First seven pairs of ribs are called true ribs or vertebrochondral ribs.
(ii) A rib has two articulation surfaces on its dorsal end and is hence called bicephalic.
(iii) Pelvic girdle consists of two coxal bones
(iv) Xiphoid process forms the lowermost and manubrium forms the uppermost part of the sternum.
Which of these are correct?
(1) (i), (ii) and (iii) (2) (ii), (iii) & (iv)
(3) (i), (iii) and (iv) (4) All are correct

*117. Go through the following matches
(i) Gluteus maximus - Chief extensor of knee
(ii) Hamstrings - Flexor of knee
(iii) Serratus anterior - Boxer's muscle
(iv) Deltoid - Flexor of shoulder joint
Which of these are correct?
(1) (i) and (iii) (2) (ii) and (iii)
(3) (i), (iii) and (iv) (4) (ii), (iii) & (iv)

118. Given below are the following statements regarding Actin
(i) Is the main constituent of light band
(ii) Forms the Anisotropic band on its own
(iii) Are the thicker filaments
(iv) Are a part of the 'H' zone.
Choose the correct option.
(1) (i), (ii) and (iii) are true
(2) (i) and (iii) are true
(3) (ii), (iii) and (iv) are false
(4) All are false

119. Read the following statements regarding muscle contraction
(i) One ATP is utilised for making and breaking of the cross bridge
(ii) The sarcomere lies between 2 Z-lines
(iii) Troponin blocks the active sites in resting stage
(iv) Ca^{++} ions help in unmasking active sites on HMM.
Choose the correct option
(1) Only (i) is false
(2) Only (ii) and (iii) are true
(3) Only (iv) is false
(4) All are true

120. Match list-I and list-II, select the correct answer using the codes given below the lists.

List-I (Contractile proteins)	List-II (Functions)
A. Myosin	1. Stabilizes F-actin
B. Actin	2. Calcium binding
C. Troponin	3. Sliding
D. Tropomyosin	4. ATPase activity

CODES :	A	B	C	D
(1)	3	4	1	2
(2)	4	3	2	1
(3)	4	3	1	2
(4)	3	4	2	1

121. Which of the following statements is consistent with smooth muscle architecture?
(1) The presence of deep, invaginating T-tubules
(2) Actin and myosin organized into visible striations
(3) Multicellular units of muscle tissue that function voluntarily

*114. Interphalangeal joint is hinge joint and metacarpophalangeal joint is angular joint.
*115. Xiphisternum is hyaline cartilage.
*116. The false ribs are called vertebrochondral ribs.
*117. Gluteus maximus is chief extensor of thigh while deltoid is abductor and extensor of shoulder.

(4) Multiunit muscle cells that are active during GI peristalsis

*122. Red muscle fibres are heavily dependent on which of the following in order to function properly?

I. Oxygen concentration
II. ATP levels
III. Intracellular glucose storage

(1) I and II only (2) II and III only
(3) III only (4) I, II and III

*123. Go through the following statements

(i) Sigmoid notch is present between condyloid process and coronoid process of mandible
(ii) The thoracic vertebrae are the strongest and the largest of all the vertebrae.
(iii) The atlas permits up and down or nodding movement of skull on it.
(iv) The body of atlas bears an odontoid process.

Which of these are correct?

(1) (i), (ii) & (iii) (2) (i), (iii) & (iv)
(3) (i) and (iii) (4) (iii) and (iv)

*124. Read the following matches carefully

(i) Greater sciatic notch - Innominate bone
(ii) Obturator foramen - Innominate bone
(iii) Acromion process - Humerus

Which of these are correct?

(1) (i) and (ii) (2) (ii) and (iii)
(3) (i) and (iii) (4) All are correct

125. Read the following matches carefully

(i) Olecranon fossa - Ulna
(ii) Greater tuberosity - Humerus
(iii) Foramen magnum - Skull

Which of these are correct?

(1) (i) and (ii) (2) (ii) and (iii)
(3) (i) and (iii) (4) All are correct

126. Go through the following matches

(i) Acetabulum - Hip bone
(ii) Ischial tuberosity - Hip bone
(iii) Maxilla - Cheek bone

Which of these are correct?

(1) (i) and (ii) (2) (ii) and (iii)
(3) (i) and (iii) (4) All are correct

*127. Go through the following matches

(i) Trochlear notch - Ulna
(ii) Capitulum - Radius
(iii) Symphysis pubis - Hip bone

Which of these are correct?

(1) (i) and (ii) (2) (i) and (iii)
(3) (ii) and (iii) (4) All are correct

*128. Go through the following matches

(i) Calcaneum – Largest bone of the foot
(ii) Intervertebral – Cartilaginous joint discs
(iii) Lateral malleolus – Femur

Which of these are correct?

(1) (i) and (ii) (2) (ii) and (iii)
(3) (i) and (iii) (4) All are correct

129. Go through the following matches

(i) Pisiform - Sesamoid bone
(ii) Symphysis pubis - Cartilaginous joint
(iii) Cuboid - Tarsal bone

Which of these are correct?

(1) (i) and (ii) (2) (ii) and (iii)
(3) (i) and (iii) (4) All are correct

*130. Go through the following matches

(i) Atlanto occipital joint – Angular joint
(ii) Incus and stapes – Ball and socket
(iii) Talus – Bone of distal row of wrist

Which of these are correct?

(1) (i) and (ii) (2) (ii) and (iii)
(3) (ii) only (4) (i) only

131. The myosin myofilament can be cleaved into a head and a tail piece. All of the following are accurate in describing the position of myosin in a sarcomere except

I. A-band is the length of a myosin myofilaments
II. A-band contains thin and thick myofilaments

*122. Red blood fibres have high myoglobin, high mitochondria and low glycogen.
*123. Lumbar vertebrae are the strongest and the largest. Odontoid process is present on the axis.
*124. Acromion process is part of scapula.
*127. Capitulum is part of humerus which articulates with head of radius.
*128. Lateral malleolus is part of fibula.
*130. Talus is tarsal bone. Joint between incus and malleus is saddle joint.

III. A-band does not include actin-binding sites

(1) I and II only
(2) II and III only
(3) III only
(4) I, II and III

*132. Read the following matches

(i) Glenoid cavity - Scapula
(ii) Bicipital tuberosity - Humerus
(iii) Styloid process - Ulna

Which of these are correct?

(1) (i) and (ii)
(2) (i) & (iii)
(3) (ii) and (iii)
(4) All are correct

133. Match the following and mark the correct option

Column I	Column II
A. Fast muscle fibres	(i) Myoglobin
B. Slow muscle fibres	(ii) Lactic acid
C. Actin filament	(iii) Contractile unit
D. Sarcomere	(iv) I-band

(1) A – (i), B – (ii), C – (iv), D – (iii)
(2) A – (ii), B – (i), C – (iii), D – (iv)
(3) A – (ii), B – (i), C – (iv), D – (iii)
(4) A – (iii), B – (ii), C – (iv), D – (i)

134. Which one of the following is showing the correct sequential order of vertebrae in the vertebral column of human beings?

(1) Cervical–lumbar–thoracic–sacral– occygeal
(2) Cervical–thoracic–sacral–lumbar– occygeal
(3) Cervical–sacral–thoracic–lumbar–coccygeal
(4) Cervical–thoracic–lumbar–sacral–coccygeal

135. Which one of the following options is incorrect?

(1) Hinge joint – between Humerus and Pectoral girdle
(2) Pivot joint – between atlas and axis
(3) Gliding joint – between the carpals
(4) Saddle joint – between carpal and metacarpals of thumb

136. Which one of the following statements is incorrect?

(1) Heart muscles are striated and involuntary
(2) The muscles of hands and legs are striated and voluntary
(3) The muscles located in the inner walls of alimentary canal are striated and involuntary
(4) Muscles located in the reproductive tracts are unstriated and involuntary

137. Which one of the following statements is true

(1) Head of humerus bone articulates with acetabulum of pectoral girdle.
(2) Head of humerus bone articulates with glenoid cavity of pectoral girdle.
(3) Head of humerus bone articulates with a cavity called acetabulum of pelvic girdle.
(4) Head of humerus bone articulates with a glenoid cavity of pelvic girdle.

138. Muscles with characteristic striations and involuntary are

(1) muscles in the wall of alimentary canal
(2) muscles of the heart
(3) muscles assisting locomotion
(4) muscles of the eyelids

139. Match the followings and mark the correct option

Column I	Column II
A. Sternum	(i) Synovial fluid
B. Glenoid Cavity	(ii) Vertebrae
C. Freely movable joint	(iii) Pectoral girdle
D. Cartilagenous joint	(iv) Flat bones

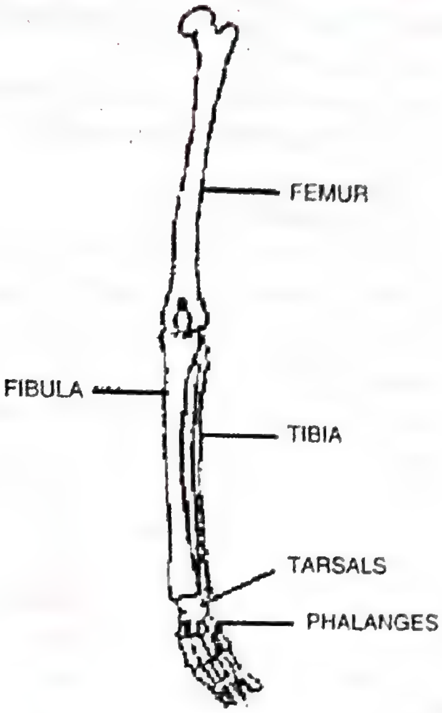
(1) A – (ii), B – (i), C – (iii), D – (iv)
(2) A – (iv), B – (iii), C – (i), D – (ii)
(3) A – (ii), B – (i), C – (iv), D – (iii)
(4) A – (iv), B – (i), C – (ii), D – (iv)

*140. Which one of the following is a sesamoid bone?

(1) Pelvis
(2) Patella
(3) Pterygoid
(4) Pectoral girdle

141. Given below is a diagram of the bones of the left human hindlimb as seen from front. It has certain mistakes in labelling.

*132. Bicipital tuberosity is a part of radius. Styloid process is also present on radius.
*140. Medial and lateral pterygoid are muscles on the side of the skull. Pisiform is another sesamoid bone.



Two of the wrongly labelled bones are
(1) Tibia and tarsals
(2) Femur and fibula
(3) Fibula and phalanges
(4) Tarsals and femur

142. **Assertion** : Inflammation of a skeletal joint may immobilize the movements of the joint.
Reason : Uric acid crystals in the joint cavity and ossification of articular cartilage lead to this.
(1) If both Assertion and Reason are true and the Reason is the correct explanation of the Assertion, then mark a.
(2) If both Assertion and Reason are true but the Reason is not the correct explanation of the Assertion, then mark b.
(3) If Assertion is true statement but Reason is false, then mark c.
(4) If both Assertion and Reason are false statements then mark d.

143. A cricket player is fast chasing a ball in the field. Which one of the following groups of bones are **directly** contributing in this movement?
(1) Femur, malleus, tibia, metatarsals
(2) Pelvis, ulna, patella, tarsals
(3) Sternum, femur, tibia, fibula
(4) Tarsals, femur, metatarsals, tibia

144. Find out the correct match regarding the structure of muscle fibre

Band	Colour	Filaments
(1) A – band	Dark	Contains only actin
(2) I – band	Light	Contains only actin
(3) A – band	Light	Contains actin and myosin both
(4) I – band	Light	Contains myosin only

(AIIMS 2011)

145. ATPase enzyme needed for muscle contraction is located in
(1) myosin (2) actin
(3) actinin (4) troponin

146. An acromian process is characteristically found in the
(1) skull of frog
(2) sperm of mammals
(3) pelvic girdle of mammals
(4) pectoral girdle of mammals

147. Which of the following pairs, is correctly matched?
(1) Fibrous joint - between phalanges
(2) Cartilaginous joint - skull bones
(3) Gliding joint - between zygapophyses of the successive vertebrae
(4) Hinge joint - between vertebrae

148. In human body, which one of the following is anatomically **correct** ?
(1) Collar bones - 3 pairs
(2) Salivary glands - 1 pair
(3) Cranial nerves - 10 pairs
(4) Floating ribs - 2 pairs

149. Which one of the following items gives its correct total number ?
(1) Cervical vertebrae in humans - 8
(2) Floating ribs in humans - 4
(3) Amino acids found in proteins - 16
(4) Types of diabetes - 3

150. Which one of the following is correct pairing of a body part and the kind of muscle tissue that moves it?
(1) Abdominal wall Smooth muscle
(2) Iris Involuntary smooth muscle
(3) Heart wall Involuntary
(4) Biceps of upper arm Smooth muscle fibres

(CBSE PRELIMS – 2008)

151. Elbow joint is an example of
(1) Gliding joint
(2) Ball and socket joint
(3) Pivot joint
(4) Hinge joint *(CBSE PRELIMS – 2009)*

152. Which one of the following is the correct matching of three items and their grouping category ?

Items	Group
(1) Actin, myosin, rhodopsin —	Muscle
(2) Cytosine, uracil, thiamine —	Pyrimidines
(3) Malleus, incus, cochlea —	Ear ossicles
(4) Ilium, ischium, pubis—	Coxal bones of pelvic girdle

153. Select the correct statement regarding the specific disorder of muscular or skeletal system
(1) *Osteoporosis* – decrease in bone mass and higher chances of fractures with advancing age
(2) *Myasthenia gravis* – Auto immune disorder which inhibits sliding of myosin filaments
(3) *Gout* – inflammation of joints due to extra deposition of calcium
(4) *Muscular dystrophy* – age related shortening of muscles
(CBSE PRELIMS – 2010)

154. Which one of the following pairs of structures is correctly matched with their correct description?

Structures		Description
(1) Tibia and fibula	-	Both form parts of knee joint
(2) Cartilage and cornea	-	No blood supply but do require oxygen for respiratory need
(3) Shoulder joint and elbow joint	-	Ball and socket type of joint
(4) Premolars and molars	-	20 in all and 3 rooted

155. Which one of the following is the correct description of a certain part of a normal human skeleton?
(1) Parietal bone and the temporal bone of the skull are joined by fibrous joint
(2) First vertebra is axis which articulates with the occipital condyles
(3) The 9th and 10th pairs of ribs are called the floating ribs
(4) Glenoid cavity is a depression to which the thigh bone articulates
(CBSE MAINS – 2010)

156. The type of muscles present in our
(1) *Heart* are involuntary and unstriated smooth muscles
(2) *Intestine* are striated and involuntary
(3) *Thigh* are striated and voluntary
(4) *Upper arm* are smooth muscle fibres fusiform in shape
(CBSE MAINS – 2011)

157. Three of the following pairs of the human skeletal parts are correctly matched with their respective inclusive skeletal category and one pair is not matched. Identify the non-matching pair.

Pairs of skeletal parts	Category
(1) Sternum and Ribs	Axial skeleton
(2) Clavicle & Glenoid cavity	Pelvic girdle
(3) Humerus and ulna	Appendicular skeleton
(4) Malleus and stapes	Ear ossicles

(CBSE MAINS – 2011)

158. Which one of the following pairs of chemical substance, is correctly categorised?
(1) Troponin and myosin - Complex proteins in striated muscles
(2) Secretin and rhodopsin – Polypeptide hormones
(3) Calcitonin and thymosin – Thyroid hormones
(4) Pepsin and prolactin – Two digestive enzymes secreted in stomach
(CBSE MAINS – 2012)

159. Acetabulum is associated with
(1) pelvic girdle (2) pectoral girdle
(3) cranium (4) vertebrae

160. Function of T-tubules in muscles is to
(1) secrete acetylcholine
(2) conduct impulses
(3) support the muscle fibres
(4) store calcium

161. The wall of the internal organs such as blood vessels, stomach and intestine contains which type of muscle tissue ?
(1) Smooth muscle fibre
(2) Cardiac muscle fibre
(3) Skeletal muscle fibre
(4) Neural tissue

162. The disease caused by accumulation of uric acid crystals outside the joints is called
(1) Gout
(2) Rheumatoid Arthirtis
(3) Osteoarthritis
(4) Rickets *(CHD. CET – 2010)*

163. Which type of joint is characterised by the presence of a fluid filled cavity and play a significant role in locomotion?
(1) Fibrous joints
(2) Cartilagenous joints
(3) Synovial joints
(4) All the above *(H.P. PMT – 2010)*

164. Joint between the carpals is called
(1) Saddle joint
(2) Gliding joint
(3) Ball and socket joint
(4) Hinge joint *(H.P. PMT – 2011)*

165. Major proteins in the thick filaments of skeletal muscle fibre is
(1) Myosin (2) Actin
(3) Tropomyosin (4) Troponin
(H.P. PMT – 2011)

166. The number of cervical vertebrae in mammals including human beings are
(1) 9 (2) 8 (3) 7 (4) 10
(H.P. PMT – 2011)

167. In the resting state, binding sites for myosin on actin filaments are masked by
(1) Troponin
(2) Light meromyosin
(3) Heavy meromyosin
(4) Calcium ions *(H.P. PMT – 2012)*

168. The number of lumbar vertebrae in human vertebral column is
(1) 26 (2) 7 (3) 12 (4) 5
(H.P. PMT – 2012)

169. ATPase activity in the muscle fibre lies with
(1) light meromyosin
(2) troponin
(3) head of heavy meromyosin
(4) short arm of heavy meromyosin
(H.P. PMT – 2012)

170. The example of pivot joint is
(1) hip joints
(2) metacarpophalangeal joints
(3) ankle joints
(4) radioulnar joints *(DUMET – 2010)*

171. The major function of the intervertebral discs is to
(1) absorb shock
(2) string the vertebrae together
(3) prevent injuries
(4) prevent hyperextension *(DUMET – 2010)*

172. The clavicle articulates with _____ of scapula
(1) acromion process
(2) glenoid cavity
(3) acetabulum cavity
(4) ball and socket joint *(DUMET – 2011)*

173. The function of Na^+ and K^+ pump is to
(1) Na^+ out and Cl^- in
(2) Cl^- out and Na^+ in
(3) Na^+ in and K^+ out
(4) Na^+ out and K^+ in *(Odisha 2009)*

174. Energy is stored in the liver and muscles in the form of
(1) carbohydrates (2) Fat
(3) protein (4) glycogen
(Odisha 2009)

175. Which is common to kidney and skeleton in mammals
(1) cortex (2) pelvis
(3) medulla (4) radius
(MP PMT 2009)

176. Axis vertebra is identified by
(1) signoid notch (2) odontoid process
(3) deltoid ridge (4) centrum
(MP PMT 2009)

177. Progressive degeneration of skeletal muscle, mostly due to genetic disorder occurs in
(1) Myasthenia gravis
(2) muscular dystrophy
(3) tetany (4) osteoporosis
(5) arthritis
(Kerala PMT 2010)

178. In human beings the cranium is formed by
(1) eight bones of which two are paired
(2) fourteen bones of which six are paired
(3) ten bones of which two are paired
(4) twelve bones of which four are paired
(AMU PMT 2010)

179. The matrix of bone and cartilage can be distinguished by the presence of
(1) Haversian canal (2) lacuna
(3) chromatophores
(4) adipose cells *(Odisha JEE 2010)*

180. The type of muscle fibre present in the wall of alimentary canal is
(1) smooth muscle fibre
(2) striped muscle fibre
(3) cardiac muscle fibre
(4) both (1) and (2) *(Odisha JEE 2010)*

181. Name the following having oxygen storing capacity
(1) myoglobin (2) actin
(3) myosin (4) fibrin
(West Bengal JEE 2011)

182. Osteomalacia is a deficiency disease of
(1) infants due to protein energy malnutrition
(2) adults due to protein energy malnutrition
(3) adults due to vitamin D deficiency
(4) infants due to vitamin K deficiency
(West Bengal JEE 2011)

183. The ball and socket joint is found in
(1) skull (2) shoulder
(3) knee (4) atlas and axis
(Odisha JEE 2011)

*184. Select the correct statement with respect to locomotion in humans
(1) The vertebral column has 10 thoracic vertebrae.
(2) The joint between adjacent vertebrae is a fibrous joint.
(3) A decreased level of progesterone causes osteoporosis in old people.
(4) Accumulation of uric acid crystals in joints causes their inflammation.
(NEET – 2013)

185. The H-zone in the skeletal muscle fibre is due to
(1) the central gap between actin filaments extending through myosin filaments in the A-band
(2) extension of myosin filaments in the central portion of the A –band.
(3) the absence of myofibrils in the central portion of A-band.
(4) the central gap between myosin filaments in the A-band *(NEET – 2013)*

186. The characteristics and an example of a synovial joint in humans is

Characteristics	Examples
(1) fluid filled synovial cavity between two bones	joint between atlas and axis
(2) lymph filled between two bones, limited movement	gliding joint between carpals
(3) fluid cartilage between two bones, limited movements	Knee joint
(4) fluid filled between two joints, provides cushion	Skull bones

(NEET – 2013)

*187. Select the correct matching of the type of the joint with the example in human skeletal system

Type of joint	Example
(1) Gliding joint	- Between carpals
(2) Cartilaginous joint	- Between frontal and parietal
(3) Pivot joint	- between third and fourth cervical vertebrae
(4) Hinge joint	- between Humerus and pectoral girdle

(AIPMT 2014)

*184. (1) Wrong as vertebral coloumn has 12 thoracic vertebrae. (2) Wrong as joint between adjacent vertebrae is a Cartilaginous joint which permits limited movements. (3) Wrong. Osteoporosis is a decrease in bone mass due to a decreased level of estrogen and not progesterone in old age. (4) Correct, as accumulation of uric acid crystals causes inflammation of joints called Gout.
*187. (a) Correct. (b) Joint between frontal and parietal is a fibrous joint. (c) Pivot joint is between Atlas and Axis (1st and 2nd) cervical vertebrae. (d) Joint between humerus and pectoral girdle is a Ball and socket joint

188. Stimulation of a muscle fiber by a motor neuron occurs at
(1) The sacroplasmic reticulum
(2) The neuromuscular junction
(3) The transverse tubules
(4) The myofibril *(AIPMT 2014)*

189. Sliding filament theory can be best explained as
(1) Actin and Myosin filaments shorten and slide pass each other
(2) Actin and Myosin filaments do not shorten but rather slide pass each other
(3) When myofilaments slide pass each other, Myosin filaments shorten while Actin filaments do not shorten
(4) When myofilaments slide pass each other Actin filaments shorten while Myosin filament do not shorten *(AIPMT 2015)*

190. Glenoid cavity articulates
(1) scapula with acromion
(2) clavicle with scapula
(3) humerus with scapula
(4) clavicle with acromion *(AIPMT 2015)*

191. Which of the following joints would allow no movement?
(1) Fibrous joint
(2) Cartilaginous joint
(3) Synovial joint
(4) Ball and Socket joint *(AIPMT Retest 2015)*

192. Which of the following is not a function of the skeletal system?
(1) Production of erythrocytes
(2) Storage of minerals
(3) Production of body heat
(4) Locomotion *(AIPMT Retest 2015)*

193. Lack of relaxation between successive stimuli in sustained muscle contraction is known as
(1) Fatigue (2) Tetanus
(3) Tonus (4) Spasm *(AIPMT/NEET 2016)*

194. Smooth muscles are
(1) involuntary, fusiform, non-striated
(2) voluntary, multinucleate, cylindrical
(3) involuntary, cylindrical, striated
(4) voluntary, spindle-shaped, uninucleate *(NEET-2-2016)*

195. Name the ion responsible for unmasking of active sites for myosin for cross bridge activity during muscle contraction.
(1) Calcium (2) Magnesium
(3) Sodium (4) Potassium *(NEET-2-2016)*

196. Osteoporosis, an age-related disease of skeletal system, may occur due to
(1) immune disorder affecting neuromuscular junction leading to fatigue.
(2) high concentration of Ca^{++} and Na^{+}
(3) decreased level of estrogen
(4) accumulation of uric acid leading to inflammation of joints *(NEET-2-2016)*

197. Out of 'X' pairs of ribs in humans only 'Y' pairs are true ribs. Select the option that correctly represents values of X and Y and provides their explanation:
(1) X = 12, Y = 7 True ribs are attached dorsally to vertebral column and ventrally to the sternum.
(2) X = 12, Y = 5 True ribs are attached dorsally to vertebral column and sternum on the two ends.
(3) X = 24, Y = 7 True ribs are dorsally attached to vertebral column but are free on ventral side.
(4) X = 24, Y = 12 True ribs are dorsally attached to vertebral column but are free on ventral side *(NEET 2017)*

198. The pivot joint between atlas and axis is a type of
(1) fibrous joint
(2) cartilaginous joint
(3) synovial joint (4) saddle joint *(NEET 2017)*

ANSWERS

1. (1)	2. (3)	3. (4)	4. (3)	5. (2)	6. (2)	7. (4)	8. (1)	9. (3)	10. (1)
11. (1)	12. (4)	13. (2)	14. (3)	15. (2)	16. (1)	17. (2)	18. (3)	19. (4)	20. (4)
21. (1)	22. (2)	23. (4)	24. (3)	25. (2)	26. (4)	27. (4)	28. (2)	29. (1)	30. (2)
31. (3)	32. (4)	33. (1)	34. (4)	35. (1)	36. (3)	37. (1)	38. (4)	39. (2)	40. (4)
41. (2)	42. (3)	43. (2)	44. (1)	45. (3)	46. (2)	47. (3)	48. (4)	49. (1)	50. (1)
51. (1)	52. (4)	53. (1)	54. (3)	55. (2)	56. (4)	57. (3)	58. (1)	59. (4)	60. (4)
61. (4)	62. (3)	63. (4)	64. (1)	65. (2)	66. (1)	67. (2)	68. (4)	69. (1)	70. (2)
71. (1)	72. (2)	73. (1)	74. (4)	75. (3)	76. (4)	77. (3)	78. (4)	79. (3)	80. (4)
81. (3)	82. (1)	83. (1)	84. (3)	85. (3)	86. (4)	87. (2)	88. (2)	89. (4)	90. (2)
91. (3)	92. (4)	93. (1)	94. (3)	95. (2)	96. (2)	97. (3)	98. (2)	99. (2)	100. (2)
101. (4)	102. (1)	103. (3)	104. (4)	105. (4)	106. (2)	107. (4)	108. (2)	109. (3)	110. (2)
111. (2)	112. (2)	113. (2)	114. (3)	115. (4)	116. (2)	117. (2)	118. (3)	119. (2)	120. (2)
121. (4)	122. (1)	123. (3)	124. (1)	125. (2)	126. (1)	127. (2)	128. (1)	129. (4)	130. (1)
131. (3)	132. (2)	133. (3)	134. (4)	135. (1)	136. (3)	137. (2)	138. (2)	139. (2)	140. (2)
141. (3)	142. (1)	143. (4)	144. (2)	145. (1)	146. (4)	147. (3)	148. (4)	149. (2)	150. (2)
151. (4)	152. (4)	153. (1)	154. (2)	155. (1)	156. (3)	157. (2)	158. (1)	159. (1)	160. (2)
161. (1)	162. (1)	163. (3)	164. (2)	165. (1)	166. (3)	167. (1)	168. (4)	169. (3)	170. (4)
171. (1)	172. (1)	173. (4)	174. (4)	175. (2)	176. (2)	177. (2)	178. (1)	179. (1)	180. (4)
181. (1)	182. (3)	183. (2)	184. (4)	185. (1)	186. (1)	187. (1)	188. (2)	189. (2)	190. (3)
191. (1)	192. (3)	193. (2)	194. (1)	195. (1)	196. (3)	197. (1)	198. (3)		

21 NEURAL CONTROL AND COORDINATION

The human body has several organs. These organs cannot perform their functions independently. So each organ depends on other organs. In order to maintain normal physiology, functions of these organs must be coordinated so that they can work in proper manner. **Coordination** is the process through which two or more organs interact and complement the functions of each other. **Integration** is a process which makes two or more organs to work as a functional unit in hormony. Thus neural system (previously called nervous system) performs two functions (i) Co-ordination and (ii) Integration.

It involves control and coordination of various body functions through neurons.

The neural system and the endocrine system jointly coordinate and integrate functions of various body parts to maintain normal physiology. The neural system provides an organized network of nerve fibres which connect various organs for quick neural coordination. The endocrine system provides chemical integration through hormones.

NEURAL SYSTEM

The neural system is the control system of the body which consists of highly specialized cells called **neurons**. The neurons detect and receive information from different sense organs (receptors) in the form of stimuli and transmit the stimuli to the central neural system (CNS) through sensory nerve fibres. The central neural system is composed of the brain and spinal cord.

Thus the neural system of higher animals performs three basic functions : (i) **receiving** sensory input from internal and external environment by sensory nerves to the CNS, (ii) **processing** the input information, in the CNS and (iii) **responding** to the stimuli transmitting motor commands from the CNS to determine the response of the body parts or cells.

The neural or nervous system is present in most of multicellular animals. It is very simple in lower invertebrates. Sponges do not have neurons. In *Hydra* all neurons are similar and joined with one another to form a nerve net forming "primitive nervous system". *Planaria* has two nerve cords (bundles of nerve fibres) that join to form a rudimentary brain. The earthworm has more evolved nervous system consisting of well developed ventral nerve cord, paired segmental ganglia and segmental nerves. Insects have well better organized nervous system, where a brain is present along with a number of ganglia and nerves. The vertebrates have more developed neural system as compaired to invertebrates. The brain is most complex and advanced in primates, particularly in human beings. This complexity of the neural system has increased during the course of evolution. It is due to the development of complex organs and systems in animals.

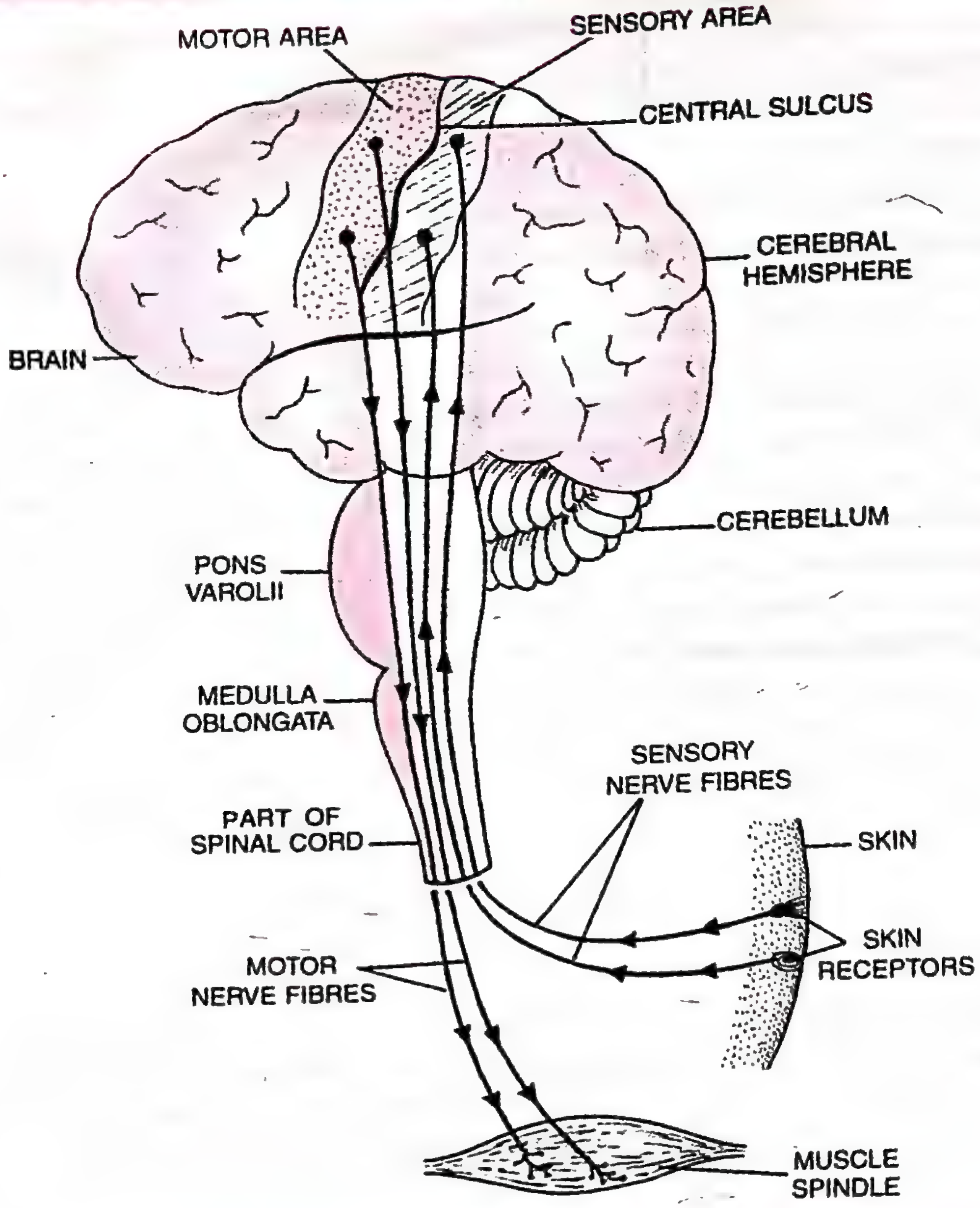


Fig. 21. 1. Diagram showing sensory and motor pathways.

HUMAN NEURAL SYSTEM

Human neural system is divisible into two main parts :

1. **Central Neural System** (CNS). It is a hollow, dorsally placed structure lying along the mid-dorsal axis of the body. It comprises the brain and spinal cord. The brain is lodged in the skull while spinal cord is enclosed by the vertebral column.

2. **Peripheral Neural System** (PNS). The nerves arising from the central neural system constitute the peripheral neural system. The nerves originate from the brain and spinal cord and are known as *cranial nerves* and *spinal nerves* respectively.

Based on their functions, the nerve fibres of PNS are divided into two groups, namely (a) **afferent nerve fibres** and (b) **efferent nerve fibres**. The afferent nerve fibres transmit sensory impulses from tissues/organs to the CNS and form the sensory or afferent pathway. The efferent nerve fibres transmit motor impulses from CNS to the concerned tissues/organs and form the motor or efferent pathways. The peripheral nervous system is again divided into two subdivisions :

(i) **Somatic Neural System.** This system includes the nerves supplying the skeletal muscles. Thus, the somatic neural system controls the movements of the body by acting on the skeletal muscles.

(ii) **Autonomic Neural System** (ANS). It controls and coördinates such organs which are under involuntary control. So, it is otherwise called involuntary neural system. It is further classified into **sympathetic** and **parasympathetic neural system.**

Visceral Neural System is the part of peripheral neural system that comprises the whole complex of nerves fibres, ganglia and plexuses by which impulses travel from the central neural system to the viscera and from viscera to the central neural system.

The bundles of nerve fibres within the CNS are called **tracts** while those present in the PNS are called **nerves.**

Neuron As Structural and Functional Unit of Neural System (Fig. 21.2)

1. **Neurons (= Nerve Cells).** A neuron is a structural and functional unit of the neural tissue and hence the neural system. Certain neurons may almost equal the length of body itself. Thus neurons with longer processes (projections) are the *longest cells* in the body. Human neural system has about 100 billion neurons. Majority of the neurons occur in the brain. Fully formed *neurons never divide* and remain in interphase throughout life. Shortly after birth, new neurons do not develop. Certain neurons have flask shaped cytons and are called **Purkinje cells**, which occur in the cerebellum of the brain.

A neuron consists of main cell body and cytoplasmic processes arising from it.

(i) **Cell body (= Cyton or Soma).** It varies in size and form. It may be up to 13.5 μm in diameter and may be irregular, spherical, oval, rounded, star-shaped or pyramidal. Like a typical cell it consists of cytoplasm, nucleus and cell membrane. It has abundant cytoplasm, called **neuroplasm** and a relatively large spherical central nucleus with a distinct **nucleolus**. The cytoplasm has mitochondria, Golgi apparatus, rough endoplasmic reticulum, ribosomes, lysosomes, fat globules, pigment granules, **neurofibrils, neurotubules** and **Nissl's granules**. Presence of neurofibrils and Nissl's granules is characteristic to all neurons. Neurofibrils play a role in the transmission of impulses. Neuro-tubules are in fact, microtubules which maintain the shape of the neuron. The Nissl's granules (also called Nissl's bodies) are irregular masses of rough endoplasmic reticulum with numerous attached and free ribosomes and polysomes. The Nissl's granules probably synthesize proteins for the cell.

Centrioles, formerly believed to be absent in mature neurons, have been described in neurons and may be associated with the production and maintenance of microtubules.

The cytoplasm immediately surrounding the nucleus is loaded with protein-synthetic machinery, and is called **perikaryon.** Previously the name perikaryon was given to the cyton (cell body or soma). Ageing neurons contain a pigment **lipofuscin** (made up of residual bodies derived from lysosomes).

Cyton is concerned with metabolic maintenance and growth.

(ii) **Neurites.** The processes of neurons are called **neurites.** These are of two types: dendrites or dendrons and an axon or axis cylinder or neuraxon.

(a) **Dendrites** (Dendrons). These are usually shorter, tapering and much branched processes. They may be one to several. The dendrites contain neurofibrils, neurotubules and Nissl's granules. They conduct nerve impulse towards the cell body and are called **afferent processes** (= receiving processes).

(b) **Axon**. Axon is a single, usually very long process of uniform thickness. The part of cyton from where the axon arises is called **axon hillock**. Most sensitive part of neuron is axon hillock. The axon contains neurofibrils and neurotubules but *does not have* Nissl's granules, Golgi complex, ribosomes, pigment granules, fat globules, etc. In the absence of Nissl's granules, the axon depends on the cell body for the supply of proteins. The cell membrane of the axon is called **axolemma** and its cytoplasm is known as **axoplasm**. The axon ends in a group of branches, the **axon terminals**. When axon terminals meet the dendrites of

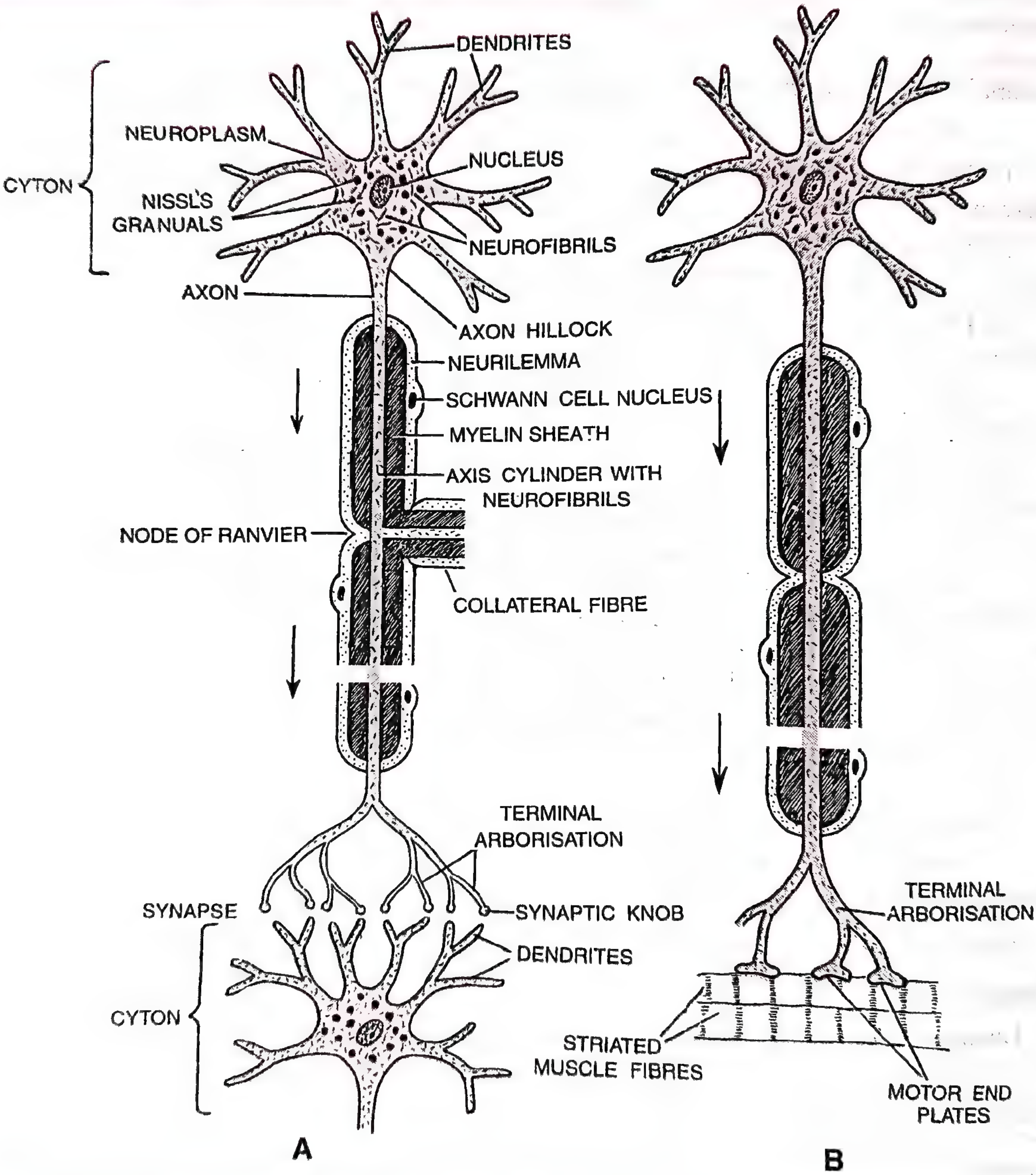


Fig. 21.2. Neurons and medullated nerve fibres. A, showing collateral fibre and synapse. B, showing motor neuron and striated muscle fibres.

another neuron to form a synapse they form **synaptic knobs** (= **end plates**). The synaptic knobs contain mitochondria and secretory vesicles. The part of the sarcolemma (muscle plasma membrane) that lies beneath the axon terminals/nerve endings, is called **motor end plate**.

Each axon may also possess side branches called **collateral fibres** which are usually much finer than the main axonal process. The axon conducts nerve impulses away from the cell body, therefore, called an **efferent process**.

There are two types of axon namely **myelinated** and **non-myelinated**. In myelinated nerve fibres **Schwann cells** form **myelin sheath** around the axon. The gaps between two adjacent myelin sheaths are called **nodes of Ranvier**. Myelinated nerve fibres are found in cranial and spinal nerves. In non-myelinated nerve fibres Schwann cells do not form myelin sheath and are without nodes of Ranvier. They are commonly found in autonomous and somatic neural systems.

Types of Neurons on the Basis of Structure (Fig. 7.36)

1. **Non-Polar Neurons**. Each neuron has several branched processes (projections). These neurons are rare in vertebrates but occur in cnidarians (coelenterates) *e.g., Hydra.*

2. **Unipolar Neurons**. The body has only one axon. It is found usually in the embryonic stage.

3. **Pseudounipolar Neurons**. A single process arises from the cyton and then divides into axon and dendrite. They are found in dorsal root ganglia of spinal nerves.

4. **Bipolar Neurons**. Each bipolar neuron has one axon and one dendrite. They are present in the retina of eye.

5. **Multipolar Neurons**. These neurons have several dendrites and an axon. They are found in cerebral cotex.

Differences between Afferent Neurons and Efferent Neurons

Afferent Neurons	*Efferent Neurons*
1. They conduct impulses from the receptors to CNS.	1. They conduct impulses from CNS to the effectors.
2. The terminals of dendrons/dendrites become modified to form receptors.	2. The axon terminals come in contact with the motor end plate (part of the sarcolemma) to form neuromotor junction.
3. They are sensory in nature.	3. They are motor in nature.

Central Neural System

As stated earlier it comprises the brain and spinal cord.

Human Brain

Location and protective coverings of the brain. The brain is the anterior most part of the central neural system which is lodged in the cranial cavity (cranium) of the skull. The human brain weighs from 1220 to 1400 grams. The human neural system has about 100 billion neurons, majority of them occur in the brain. The brain is covered by three membranes or **meninges*** (sing. meninx). The innermost membrane, the **piamater** is thin, very delicate and vascular and invests the brain closely. The next is **arachnoid membrane** (also called

*Inflammation of the meninges is called **meningitis**.

arachnoid mater),which is a thin "spider webby" structure from which it gets its name. The outermost membrane, the **duramater** is the tough fibrous membrane adhering closely to the inside of the skull. Between the arachnoid membrane and pia-mater is a space known as **sub-arachnoid space**. The space which is present between the arachnoid and duramater is called **subdural space**. The sub-arachnoid space is filled with **cerebrospinal fluid**. This fluid serves as a pad to cushion the central nervous system from shocks. It also provides a medium for exchange of food materials, wastes, respiratory gases and other materials. The subdural space contains a little fluid which is not cerebrospinal fluid. The membranous areas between the cranial bones of the foetal skull are called **fontanels**.

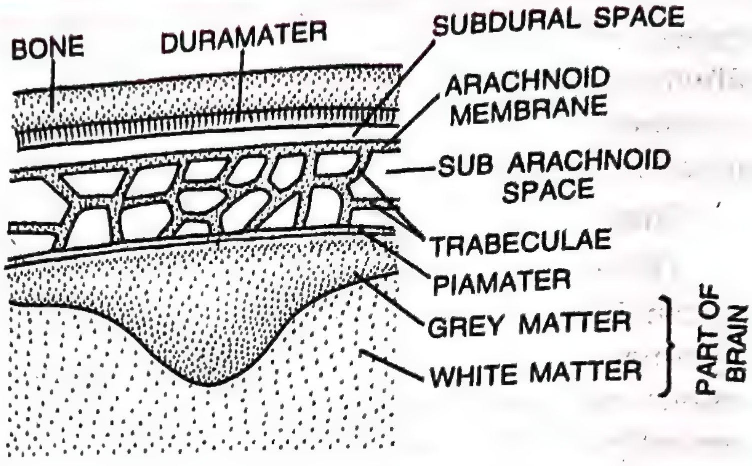


Fig. 21.3. Diagram showing meninges, grey matter and white matter of brain.

Structure and Functions of Human Brain

The human brain is divisible into three parts.

1. **Fore brain** or **Prosencephalon** includes olfactory lobes, cerebrum and diencephalon.
2. **Mid brain** or **Mesencephalon** comprises corpora quadrigemina and crura cerebri.
3. **Hind brain** or **Rhombencephalon** consists of cerebellum, pons varolii and medulla oblongata.

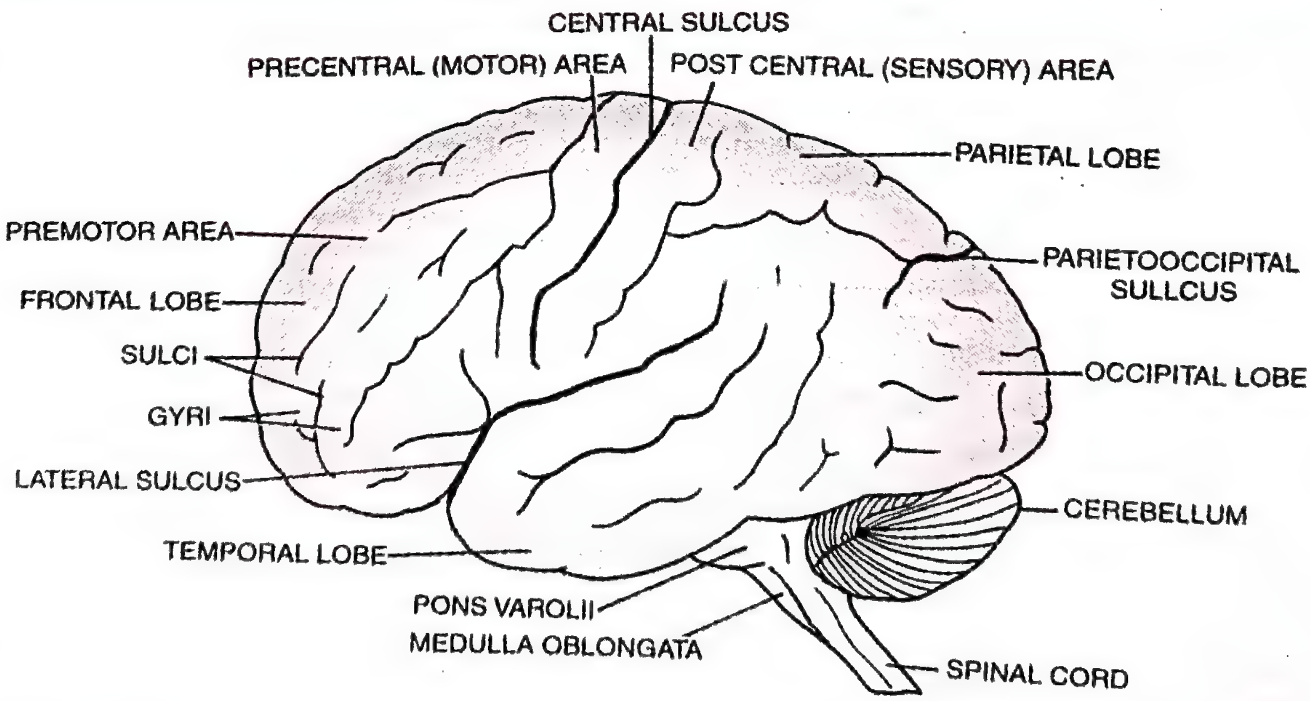


Fig. 21.4. Human brain in lateral view.

Fore Brain

(i) **Olfactory lobes.** The anterior part of the brain is formed by a pair of short club-shaped structures, the olfactory lobes. Each lobe consists of two parts, an anterior **olfactory bulb** and a posterior **olfactory tract**. They are fully covered by the cerebral hemispheres and are, therefore, only visible in the ventral view of the brain. A pair of olfactory nerves arises from the olfactory lobes.

Function. Olfactory lobes are concerned with the sense of smell.

(ii) **Cerebrum.** The cerebrum is the largest and most complex of all the parts of the human brain. It consists of left and right hemispheres connected by a large bundle of myelinated fibres, the **corpus callosum** and other smaller fibre bundles. Anteriorly the corpus callosum is folded back to form the **genu.** Posteriorly the corpus callosum curves ventrally to form rounded **splenium** which joins a fibrous strip called **fornix.** The fornix is a paired structure, one of which is present in each hemisphere. Left cerebral hemisphere is smaller than the right.

Cerebral Cortex. The outer portion of cerebrum is called the **cerebral cortex** that makes up the grey matter of the cerebrum. The surface of the cortex is greatly folded. The upward folds, or **gyri** (sing. gyrus), alternate with the downward grooves, or **sulci** (sing. sulcus). Beneath the grey matter there are present millions of medullated nerve fibres, connecting the neurons of the cerebral cortex with those located elsewhere in the brain. The large concentration of medullated nerve fibres gives this tissue an opaque white appearance. Hence they are collectively called **White matter.**

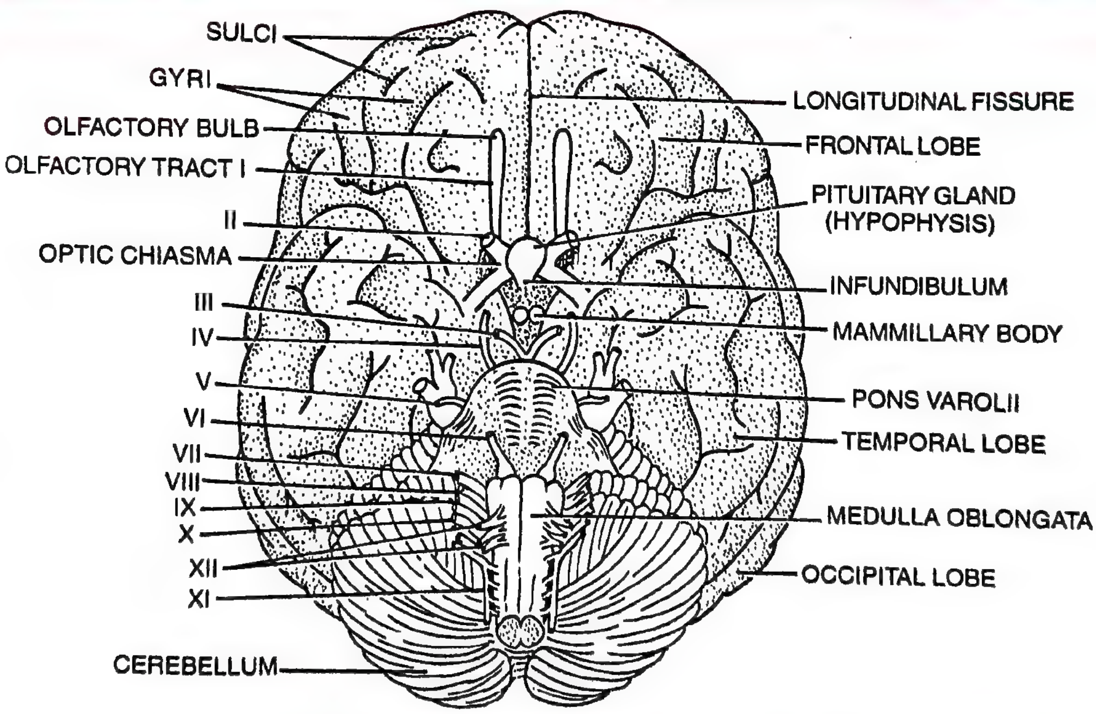


Fig. 21.5. Human brain in ventral view. The numbers I to XII indicate the cranial nerves.

Lobes. A very deep fissure, the **longitudinal fissure,** separates the two cerebral hemispheres. Each cerebral hemisphere of the cerebrum is divided into four lobes: **frontal, parietal, temporal** and **occipital lobes.** The **central sulcus** separates the frontal lobe from the parietal lobe. The **lateral sulcus** separates the frontal lobe from the temporal lobe. The **parieto-occipital sulcus** separates the parietal lobe from the occipital lobe.

Functional Areas of the Cerebrum. In each cerebral hemisphere, there are present three types of functional areas : (a) **Sensory areas.** They receive impulses from the receptors. (b) **Association areas.** They interpret the input, store the input and initiate a response in light of similar past experience. Thus the associated areas are involved in memory, learning and reasoning. (c) **Motor areas.** They transmit impulses to the effectors.

The **precentral (motor) area** lies in the frontal lobe immediately anterior to the central sulcus. The nerve cells are called pyramidal cells which initiate the contraction of voluntary muscles. The **post central (sensory) area** (= somaesthetic area) lies in the parietal lobe immediately posterior to the central sulcus. It perceives sensations of pain, temperature, pressure and touch. The **sensory speech area** is situated in the lower part of the parietal lobe and extends into the temporal lobe. It perceives the spoken word. The **auditory** (hearing) **area** lies immediately below the lateral sulcus in the temporal lobe. It is the centre for hearing. **Wernicke's area** is usually located in the left temporal lobe that plays a role in understanding speech and writing words. The **visual area** lies in the greater part of occipital lobe. It is the centre for sight. The **olfactory** (smell) **area** lies deep within the temporal lobe. It receives the impulses from the nose via olfactory nerve and interprets them. The **taste area lies** in the parietal lobe above the lateral sulcus in the

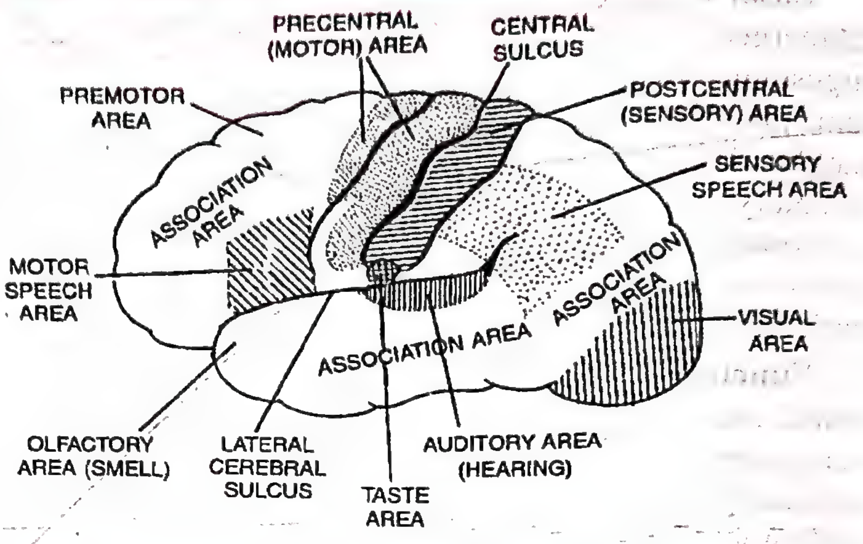


Fig. 21.6. A cerebral hemisphere (half of the cerebrum) showing the functional areas.

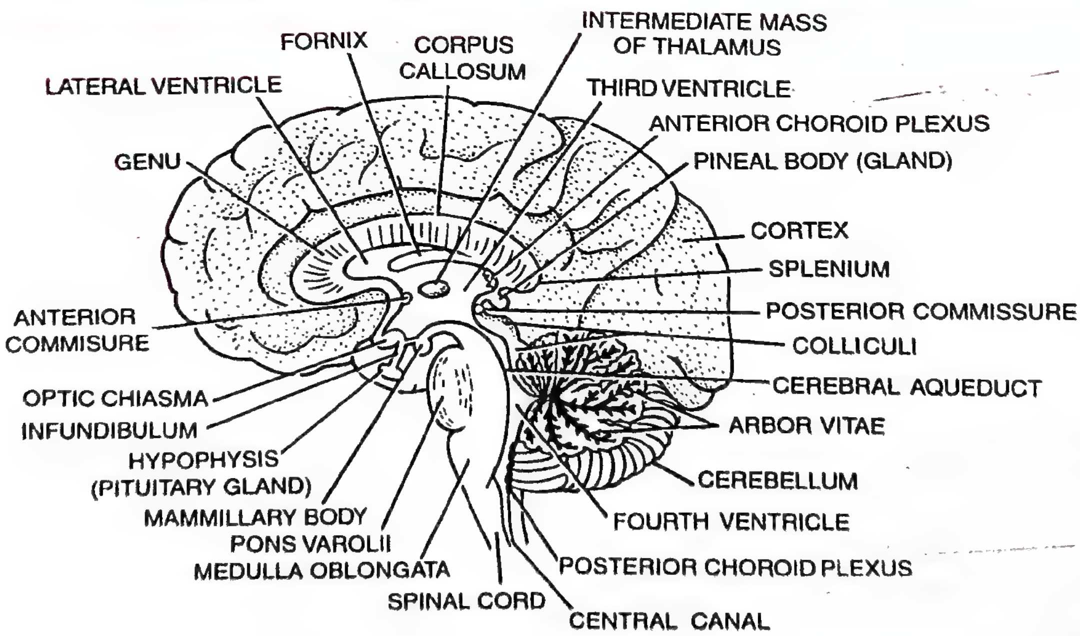


Fig. 21.7. Median section of human brain.

post central (sensory) area. The nerve impulses from the tongue are interpreted here. The **motor speech area** (also called **Broca's motor speech area**) lies in the frontal lobe. Other functional areas of the cerebrum include the **visual association area** in the occipital area, **parietal association area** in the parietal lobe, the **frontal association area** in the frontal lobe and **temporal association area** in the temporal lobe. (An association area is a portion of the cerebral cortex that neither receives direct sensory stimuli nor directly initiates motor impulses; instead, it appears to process and interpret sensory impulses).

Basal Ganglia (= Basal Nulcei). Basal ganglia are the scattered masses of grey matter, submerged in the subcortical substance of cerebral hemispheres. The **corpus striatum**, the largest nucleus in the basal ganglia is a mass of grey matter situated at the base of the cerebral hemispheres in close relation to the thalamus. The **lenticular nucleus** is also a part of basal ganglia. The main functions of the basal ganglia are (i) control of the movements during voluntary motor activity, (ii) control of reflex muscular activity, (iii) control of muscle tone, (iv) control of automatic associated movements and (v) role in arousal mechanism. Parkinson's disease occurs due to damage of the basal ganglia. Wilson's disease is due to damage of the lenticular nucleus.

Functions. Each lobe of cerebral hemisphere performs specific functions. (a) In the frontal lobe creative ideas occur. (b) In the temporal lobe sounds are interpreted so that one can understand what is being spoken. (c) In the parietal lobe feelings about touch, hot and cold and pain are registered. It is this area that allows to accurately follow directions on map, reading a clock or dressing a person. (d) The occipital lobe is where eyes see, and interpret what is seen.

A summary of major functions of cerebral lobes has been given below.

Cerebral Lobe	Major Functions
Frontal lobe	Inner monitoring of complex thoughts and actions, creative ideas, translation of perceptions and memories into plans of muscle movement, reality testing by judgement, *controls intellectual ability* to abstract, reasoning, decision making, expression of emotions, willpower and personality.
Parietal lobe	Registration of sensory perception of touch, pain, heat and cold, knowledge about position in space, taking in information from environment, organising it and communicating to rest of brain.
Temporal lobe	Decoding and interpretation of sound, language comprehension, smell, memory and emotion.
Occipital lobe	Decoding and interpretation of visual information; shape and colour.

(iii) **Diencephalon.** Its main parts are **epithalamus, thalamus** and **hypothalamus.** Epithalamus is thin and not formed of nervous tissue. Its anterior part is vascular and folded to form the **anterior choroid plexus.** Just behind the anterior choroid plexus, the epithelium forms a short stalk, the **pineal stalk** which has a rounded body, the **pineal body**, at its tip. The pineal body is an endocrine gland and, therefore, secretes a hormone, named **melatonin.** The thalamus, which lies superior to the mid brain is composed primarily of grey matter. The optic nerves which come from the eyes, form a crossing, the **optic chiasma** in front of the hypo-thalamus. The **hypophysis (pituitary gland)** is directly

attached to the hypothalamus by a stalk, the **infundibulum.** The pituitary gland is an endocrine gland and secretes certain hormones. Behind the infundibulum, a pair of small rounded eminences, the **mammillary bodies** are present. They are like nipple and hence their name.

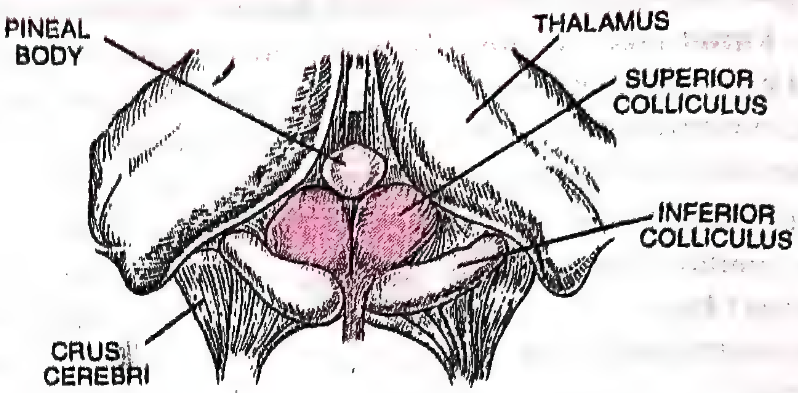


Fig. 21.8. Part of Human brain in posterior view to show some structures in detail.

Functions of Hypothalamus. Although hypothalamus is relatively small (4 grams, about 1/300 of the total brain mass) yet it is highly vascular. It integrates and controls the visceral activities. It maintains homeostasis. It provides anatomical connection between the nervous and endocrine systems by its relationship to the pituitary gland. Neuroendocrine role of the hypothalamus is described in the next Chapter. Through connections with pituitary gland, it controls growth and sexual behaviour. Hypothalamus is thermoregulatory centre. Hence it is called "thermostat" of the body. It keeps body temperature at roughly 37°C by means of a complex thermostat system. It is also associated with behavioural activities. Appetite, thirst and satiety (feeling of being satisfied) centres are located in the hypothalamus. It also influences respiration and heart beat.

Mid Brain

(i) **Corpora quadrigemina.** The upper or superior surface of the mid brain has two pairs of rounded protrusions collectively called the **corpora quadrigemina;** one pair is called **superior colliculi** and the other pair is called **inferior colliculi.** The superior and inferior colliculi of each side are termed the **corpora bigemina.**

Functions. The superior colliculi are concerned with the sense of sight. However, the inferior colliculi are concerned with hearing.

(ii) **Cerebral peduncles** (Crura cerebri). These are two bundles of fibres which lie on the lower or inferior surface of the mid brain.

Function. They relay impulses back and forth between the cerebrum, cerebellum, pons and medulla.

Hind Brain

(i) **Cerebellum.** The second largest part of the human brain is the **cerebellum** (means simply "little cerebrum"). It is well developed in human brain. It consists of two lateral **cerebellar hemispheres** and central worm-shaped part, the **vermis.** Like the cerebrum, the cerebellum has its grey matter on the outside, comprising three layers of cells and fibres. The middle layer contains characteristically large flask shaped **Purkinje cells.** The Purkinje's cells rank among the most complex of all neurons. The cerebellum also has **Golgi cells, basket cells** and **granule cells.**

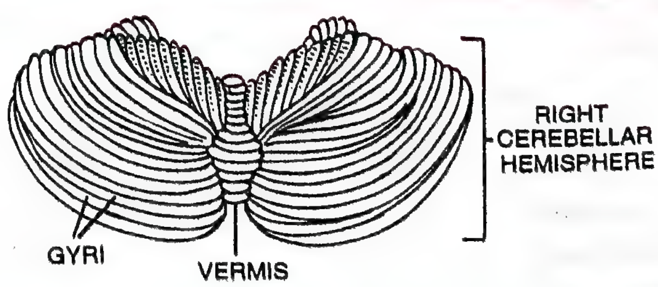


Fig. 21.9. The cerebellum viewed from below.

A cross section of the cerebellar hemispheres shows a branching tree like arrangement of grey and white matter called the **arbor vitae** ("tree of life").

Functions. The cerebellum controls rapid muscular activities, such as running, typing and even talking. All activities of the cerebellum are involuntary, but may involve learning in their early stages. Alcohol affects the cerebellum. Since, alcohol is a depressant, it interferes with the functions of the cerebellum.

(ii) **Pons Varolii.** It is situated in front of the cerebellum below the mid brain and above the medulla oblongata. It consists mainly of nerve fibres which form a bridge (**pons**—bridge) between the two hemispheres of the cerebellum and of fibres which pass between the higher levels of the brain and the spinal cord. Pneumotaxic centre is present in pons varolii.

Functions. Pons varolii relays impulses between the medulla oblongata and more superior part of the brain, between the hemispheres of the cerebellum and between the cerebrum and cerebellum. The pneumotaxic centre limits inspiration.

(iii) **Medulla oblongata.** It extends from the pons varolii above and is continuous with the spinal cord below. Its shape is like a pyramid. The medulla oblongata has a very thin, non-vascular folded structure on its lower side called the **posterior choroid plexus.**

Functions. Medulla oblongata receives and integrates signals from spinal cord and sends resulting signals to the cerebellum and thalamus. It contains centres that regulate heart rate, blood pressure, breathing, swallowing, salivation, sneezing, vomiting and coughing and some other involuntary movements.

Brain Stem. The mid brain, pons varolii and medulla oblongata are collectively called the **brain stem**, connecting the fore brain and spinal cord.

Limbic System

Components of Limbic System. Certain components of the cerebrum and diencephalon constitute the **limbic system** (*limbus* L. a border or edge or fringe of a part). Its main components are the following (i) **Hippocampus.** Its shape roughly resembles the sea horse. It is located inside the temporal lobe (ii) **Amygdala** or **Amygdaloid nucleus** (L., Gr. *amygdale* – almond). It is almond shaped and is located in the tip of the temporal lobe. (iii) **Septal nuclei.** These are located within the septal area formed by the regions under corpus callosum and the paraterminal gyrus (a cerebral gyrus). (iv) **Mamillary bodies.** These are present behind the infundibulum. (v) **Basal ganglia.** They are scattered masses of grey matter.

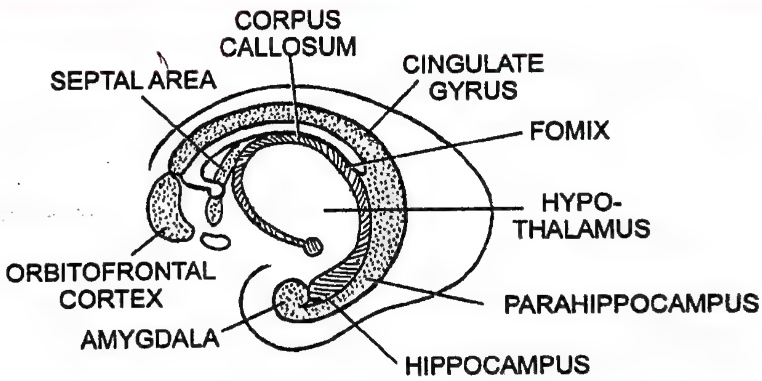


Fig. 21.10. The Limbic System

Functions of limbic system. (a) It is sometimes called the **"emotional brain"** because it controls emotional behaviour expressed in the form of joy, sorrow, fear, fight, friendship, liking and disliking. (b) It controls food habits necessary for survival of the individual. (c) It also controls sex behaviour necessary for survival of the species.

Ventricles of the Brain

The **ventricles** consist of four hollow, fluid filled spaces inside the brain. A **lateral**

ventricle lies inside each hemisphere of the cerebrum. Each lateral ventricle is connected to the third ventricle by an **interventricular foramen (foramen of Monro)**. The **third ventricle** consists of a narrow channel between the hemispheres through the area of the thalamus. It is connected by the **cerebral aqueduct** or **aqueduct of Sylvius or iter** in the midbrain portion of the brainstem to the fourth ventricle in the pons and medulla. The **fourth ventricle** is continuous with the central canal of the spinal cord. Three openings in the roof of the fourth ventricle, a pair of **lateral apertures (foramina of Luschka)** and a **median aperture (foramen of Magendie)** allow cerebrospinal fluid to move upward to the subarachnoid space that surrounds the brain and spinal cord.

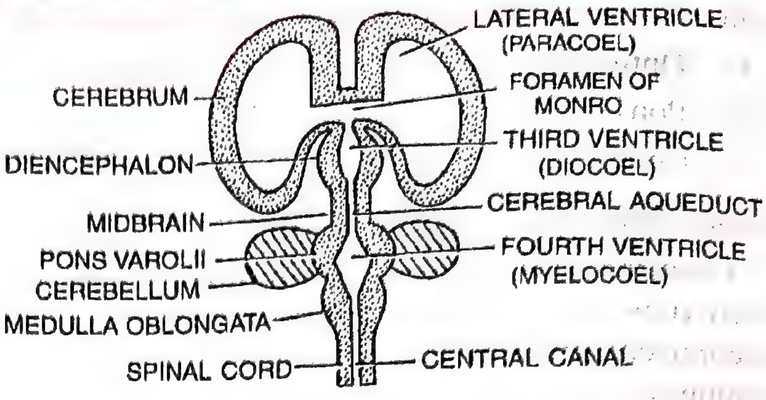


Fig. 21.11. Schematic representation of the ventricles of human brain.

Ventrolateral wall of each paracoel appears striated and hence called **corpus striatum**.

Cerebrospinal Fluid (CSF)

The cerebrospinal fluid is secreted by anterior choroid plexus and posterior choroid plexus and is found inside the ventricles of the brain, the central canal of the spinal cord and in the subarachnoid space around the brain and spinal cord. The cerebrospinal fluid performs the following functions :

(i) **Protection of the Brain and Spinal cord.** CSF protects the delicate brain and spinal cord by providing shock-absorbing medium. It acts as cushion jolts to the central nervous system.

(ii) **Buoyancy to the Brain.** Since the brain is immersed in the CSF, the net weight of the brain is reduced from about 1.4 kg to about 0.18 kg. Thus the pressure at the base is reduced.

(iii) **Excretion.** CSF carries harmful metabolic wastes, drugs and other substances from the brain to the blood.

(iv) **Endocrine Medium for the Brain.** Certain hormones are released into CSF. These hormones are carried to different parts of the brain by CSF where they may act.

Differences between Cerebrum and Cerebellum

Cerebrum	*Cerebellum*
1. It is a part of fore brain.	1. It is a part of hind brain.
2. It consists of two cerebral hemispheres.	2. It consists of two cerebellar hemispheres and a vermis.
3. Arbor Vitae is absent in cerebrum.	3. Arbor vitae is present in cerebellum.
4. It contains various functional areas. It is mainly concerned with intellligence, memories, etc.	4. It maintains posture and equilibrium.

Mammalian Characters in Human Brain

(i) Olfactory lobes are small and solid.

(ii) Cerebral hemispheres are quite large in size and divided into lobes.
(iii) Corpus callosum is also found.
(iv) Optic lobes are solid and further divided into corpora quadri-gemina.
(v) Pons varolii is present.
(vi) Cerebellum is very much folded and solid.

Human Spinal Cord (Myelon)

Location and coverings (Meninges). It is a posterior part of central nervous system which runs mid-dorsally within the vertebral column. It lies in the neural canal of the vertebral column. The spinal cord is surrounded by the same three protective membranes (meninges) as found in the brain, *viz.*, a thin innermost **piamater,** the middle webby **arachnoid membrane** (arachnoid mater) and the outer tough **duramater.** The subarachnoid space is filled with cerebrospinal fluid. There is an additional space, **the epidural space** above the dura mater. The epidural space contains fatty and connective tissues and veins.

External Structure. The spinal cord extends from the medulla oblongata. It is continuous, to the level of the second lumbar vertebra. In an adult the spinal cord is from 42 to 45 centimeters long. Its diameter varies at different levels, being enlarged in the cervical and lumbar regions. The cord is also flattened. The **cervical enlargement** extends from the fourth cervical to the first thoracic vertebrae; it is the region from which nerves supplying the arms arise. It may seem strange that the lumbar enlargement should be in the thoracic region; this is the case because the spinal cord grows at a slower rate than the vertebral column. By adulthood the area within the vertebral column below the second lumbar vertebra contains spinal nerves that branch from the spinal cord at higher levels. These spinal nerves are collectively called, the **cauda equina**, or "horse's tail". The spinal cord ends as the **conus medullaris.** The conus medullaris ends at the level of the intervertebral disc between the first and second lumbar vertebral in adults. Actually the conus medullaris is a conical portion of lower spinal cord. From the conus medullaris a fine connective tissue filament, the **filum terminale,** extends down to the coccygeal region. The filum terminale consists mostly of pia mater. The spinal cord does not extend to the coccygeal region because during development the vertebral column elongates more rapidly than the spinal cord. The **filum terminale** anchors the spinal cord within the vertebral column. Infact, the filum terminale is a long slender filament at the end of the spinal cord.

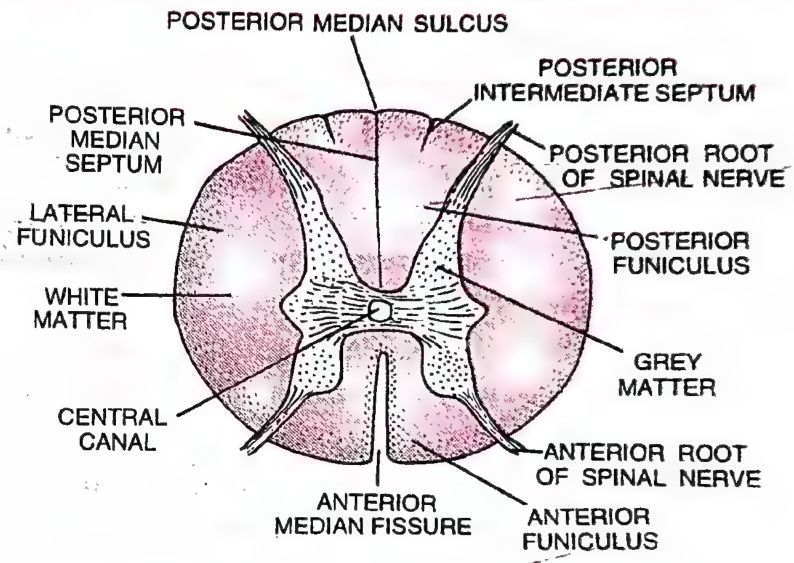


Fig. 21.12. T.S. Human spinal cord.

Internal Structure. The internal anatomy of the spinal cord is best seen in cross section. Two indentations, the **posterior median sulcus** and the **anterior median fissure,** separate the spinal cord into left and right symmetrical halves. The inner butterfly-shaped area is the **grey matter** of the spinal cord. Grey matter is so named because it lacks myelin

and therefore, appears grey in an unstained preparation. Surrounding the grey matter are bundles of myelinated nerve fibres, called fasciculi or white columns, which together form the **white matter** of the spinal cord.

In each segment of the spinal cord a spinal nerve arises from each side of the cord. Each spinal nerve connects with the cord through two nerve roots. The **dorsal nerve root** consists of a bundle of sensory axons (carrying incoming signals) whose cell bodies are located in the **dorsal root ganglion.** These axons extend into the **posterior horn** of the grey matter, where they often form synapses with other neurons, some of which are called interneurons. **Interneurons,** short neurons confined to the grey matter of the cord, form synapses with other interneurons and with the motor neurons whose cell bodies are located in the **anterior horn** of the grey matter. Aggregations of motor axons (carrying outgoing signals) from these cell bodies form the **ventral nerve roots.** The **lateral horns** lie between the anterior and posterior horns. The hollow **central canal** contains cerebrospinal fluid.

Spinal tracts. Along the white matter of the spinal cord there are two kinds of fasciculi, or bundles of axons, the **ascending tracts,** which carry sensory impulses to the brain, and the **descending tracts,** which carry motor impulses from the brain to the spinal nerves at various levels of the cord.

Functions of Spinal Cord. Spinal cord performs two main functions:

(i) The stimuli are passed from and to the brain through the spinal cord.

(ii) It is the centre of spinal reflex action.

Differences between Grey Matter and White Matter

Grey Matter	*White Matter*
1. Greyish in colour.	1. White in colour due to presence of fatty myelin sheath.
2. Comprises of cell bodies, dendrites and synapses of neurons.	2. Consists of nerve fibres (axons) arising from or to the nerve cells in grey matter.
3. Grey matter is situated on the surface, while white matter is located deeper.	3. In the spinal cord, white matter forms the outer layer and grey matter is located deep into the core.

Peripheral Neural System

The nerves which originate from the central nervous system and connect either receptor or effector organs, form peripheral neural system. Those nerves which arise from brain are called **cranial nerves** while the nerves originating from the spinal cord are termed as **spinal nerves.**

Cranial Nerves

These nerves are so named because they pass through various foramina (openings) in the cranial bones (bones of the brain box). There are present 12 pairs of cranial nerves in man.

I. **Olfactory Nerve.** Its nerve fibres arise in the olfactory epithelium of the nasal chamber. It enters the olfactory bulb of olfactory lobes of the brain. From the olfactory bulb, the nerve fibres run through the olfactory tract and ultimately reach the temporal lobe of the cerebrum. It is sensory nerve which carries impulses of smell from olfactory epithelium to the brain.

II. **Optic Nerve.** The optic nerve fibres originate in the retina of the eye and combine to form the optic nerve. Two optic nerves meet at the floor of the diencephalon where they appear to cross to opposite side and X-shaped structure thus formed is called the **optic chiasma.** Only a relatively small portion of the fibres of the optic nerves actually cross at the chiasma, many of them simply bending and remaining on the same side of the brain. Optic nerve fibres lead to the occipital lobe of the brain. It is sensory nerve and carries impulses of sight from the retina to the brain.

III. **Oculomotor Nerve.** This nerve has a name meaning "eye mover" because it supplies four of the six extrinsic eye muscles that move the eye ball in the orbit. It arises from the floor of the midbrain. It innervates four eye muscles, *viz.*, **inferior oblique, superior rectus, inferior rectus and medial rectus** (Fig. 21.13). It is a motor nerve and carries impulses from the brain to these muscles for controlling the movements of eye-ball.

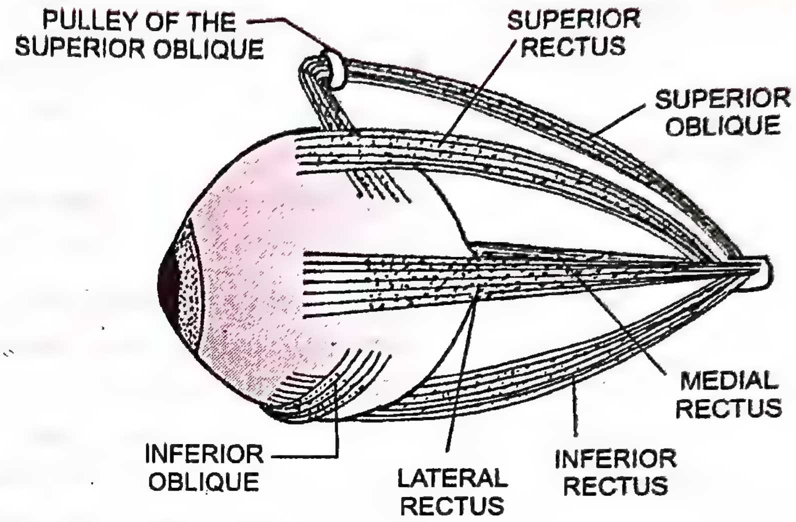


Fig. 21.13. Eye muscles.

IV. **Trochlear Nerve.** This nerve's name means "pulley" because it innervates an extrinsic eye muscle that loops a pulley-shaped ligament in the orbit. The trochlear nerve is the *thinnest* and *smallest* cranial nerve. It originates from the floor of the midbrain. It supplies nerve fibres to the **superior oblique** eye muscle (Fig. 21.13). It is a motor nerve and helps in controlling the movement of the eye-ball.

V. **Trigeminal Nerve.** It is the *largest* cranial nerve. It arises from the ventral surface of the pons varolii. It bears a **trigeminal (Gasserian) ganglion** at its origin and divides into three branches.

(a) **Ophthalmic Nerve.** It is the smallest branch of trigeminal nerve. It runs forward through the eye orbit and innervates the lacrimal glands, the conjunctiva of the eye, the forehead, the eyelids, etc. It is sensory nerve and carries impulses of touch from the above mentioned areas to the brain.

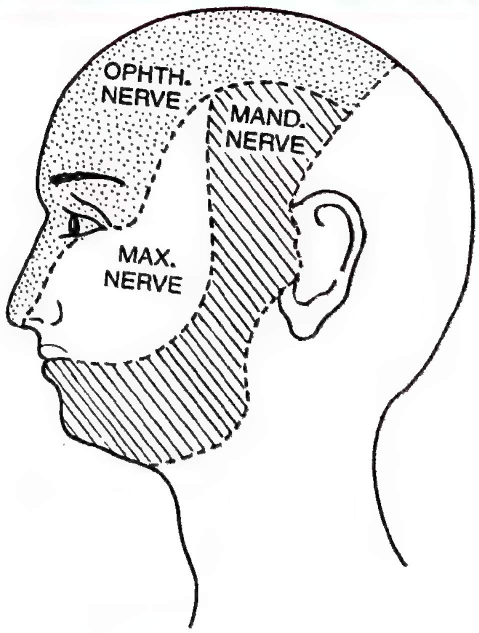


Fig. 21.14. Distribution of Trigeminal Nerve.

(b) **Maxillary Nerve.** It innervates the cheeks, the upper gums, the upper teeth and lower eyelids. It is a sensory branch and carries stimuli from these areas.

(c) **Mandibular Nerve.** It is the largest branch of trigeminal nerve. It distributes nerve fibres to the teeth and the gums of the lower jaw, the pinna of the ear, lower lip and the tongue. It is a mixed branch having both sensory and motor fibres that help in controlling these particular organs.

*Oculomotor cranial nerve originates from the **Edinger Westphal Nucleus.**

VI. **Abducens Nerve.** This nerve is named because it controls the extrinsic eye muscle that *abducts* the eye ball (turns it laterally). It originates from the pons varolii. It innervates the **lateral rectus muscle** (Fig. 21.13) of the eye ball. It is a motor nerve and controls the movements of the eye-ball.

VII. **Facial Nerve.** It arises from the lower part of the pons varolii. It bears **geniculate ganglion.** It innervates the taste buds of the tongue and muscles of the face. It also innervates the salivary glands. It is mixed nerve. It conveys impulses from the taste buds. It also controls the facial expression.

VIII. **Vestibulocochlear Nerve (Auditory Nerve).** It comes from the internal ear (membranous labyrinth) and joins the lateral side of the pons varolii. It is formed by two branches.

(a) **Vestibular Nerve.** It arises from the vestibular part of the membranous labyrinth, (utricle, saccule and semicircular canals). It is a sensory branch which is concerned with equilibrium of the body.

(b) **Cochlear Nerve.** It originates in the cochlear part of the membranous labyrinth. It is also a sensory branch and is concerned with hearing.

IX. **Glosso-pharyngeal Nerve.** It originates from the side of medulla oblongata. It innervates the taste buds, soft palate, pharynx, tongue and muscles of the pharynx. It is a mixed nerve. It controls secretion of saliva, sense of taste and movement of the pharynx.

X. **Vagus Nerve.** This nerve's name means "wanderer" (as in vagabond) and it is the only cranial nerve to extend beyond the head and neck into the thorax and abdomen. It is the *longest* cranial nerve. It originates from the side of the medulla oblongata. It bears **vagus ganglion**. It innervates the pharynx, larynx, oesophagus, stomach, lungs, heart and intestines. It is a mixed nerve. It controls the visceral sensations, and visceral movements (peristalsis, sound production, respiratory movements, heart beat).

XI. **Accessory Nerve.** Formerly it was called the **spinal accessory**. It differs from all other cranial nerves because it originates from *both* the brain (medulla oblongata) and the spinal cord. It is formed by union of its cranial and spinal roots but these are associated for a short distance only. It arises from the side of the medulla oblongata. It is a motor nerve which innervates the muscles of the pharynx, larynx, neck and shoulder and controls the movements of these organs.

XII. **Hypoglossal Nerve.** It originates from the ventral side of the medulla oblongata. It innervates the muscles of the tongue and hyoid apparatus. It is a motor nerve which controls the movements of the tongue.

Spinal Nerves

Number. Thirty one pairs of spinal nerves are named and numbered according to the vertebrae with which they are associated. They include eight pairs of **cervical** nerves, twelve pairs of **thoracic** nerves, five pairs of **lumbar** nerves, five pairs of **sacral** nerves, and one pair of **coccygeal** nerves.

Structure. The **spinal nerves** are formed by the union of the dorsal and ventral roots shortly after they leave the spinal cord. Each spinal nerve has afferent (sensory) and efferent (motor) fibres; in general, efferents come from the ventral root, and afferents go into the dorsal root. Thus, all spinal nerves are **mixed nerves** because they carry both sensory and motor impulses.

Distribution. After passing through the **intervertebral foramen**, each spinal nerve separates into posterior and anterior branches. The **posterior branch** innervates the muscles and skin of the posterior portion of the body. The **anterior branch** innervates the limbs and the lateral and anterior portions of the body.

The lumbar, sacral and coccygeal nerves leave the spinal cord before its termination at the level of the first lumbar vertebra and extend downwards inside the vertebral canal in the subarachnoid space below this level. In this way they form a sheaf of nerves which resembles a horse's tail, called the **cauda equina**. These nerves leave the vertebral canal at the appropriate lumbar, sacral or coccygeal level.

Certain spinal nerves join to form the following plexuses : (*i*) **Cervical Plexus.** It innervates the neck and diaphragm. (ii) **Brachial Plexus.** It connects the chest and arm. (*iii*) **Lumbar Plexus.** It innervates the legs. (iv) **Sacral Plexus.** It connects the pelvic region. (v) **Coccygeal Plexus.** It also innervates the pelvic region.

Autonomic Neural System

This system controls and coordinates the involuntary activities of various organs. This system is autonomous in the sense that it regulates such activities of the body in which the will power of the animal is not involved, *e.g.*, the secretion of the digestive fluid is always under the control of autonomic nervous system but the animal is not aware of it. The autonomic neural system is divisible into two parts : sympathetic neural system and parasympathetic neural system.

Sympathetic Neural System

Sympathetic neural system (Fig. 21.15) consists of the following parts :

(i)**Sympathetic chains.** They are paired chains of 21 ganglia which extend from the upper cervical level to the sacrum. Each sympathetic chain possesses 3 cervical, 12 thoracic, 5 lumbar and 1 sacral ganglia.

(ii) **Preganglionic fibres.** These are the axons of the neurons present in the spinal cord. They may synapse directly with the postganglionic neuron in the chain ganglia. They may extend through the chain ganglia to collateral ganglia. They may synapse directly or extend to the collateral ganglia. The preganglionic fibres of the sympathetic nervous system occur only in the thoracic and lumbar regions. Thus sympathetic nerves arise from the **thoracolumbar** region of the neural system.

(iii) **Collateral ganglia.** There are three collateral or prevertebral ganglia situated in the abdominal cavity close to the origins of arteries of the same names. They are the **coeliac ganglion**, the **superior mesenteric ganglion** and the **inferior mesenteric ganglion**.

(iv) **Postganglionic fibres.** These are the axons of neurons which may have their cell bodies, either in one of the chain ganglia or in one of the collateral ganglia.

Developmentally, the adrenal medullae and sympathetic ganglia are derived from the same tissue, the neural crest. The adrenal medullae are modified sympathetic ganglia and their cells are similar to the sympathetic post ganglionic neurons. Upon stimulation by the sympathetic preganglionic neurons, the adrenal medullae release about 80% **adrenaline (= epinephrine)**, 20% **noradrenaline (= norepinephrine)** and a trace amount of **dopamine.** Since sympathetic postganglionic neurons release adrenaline, noradrenaline and dopamine, they are called **adrenergic**. The sympathetic nerves stimulate the adrenal glands to secrete their hormones. Thus sympathetic nerves function with the adrenal glands as a well-integrated **sympatheticoadrenal system** having wide spread effects.

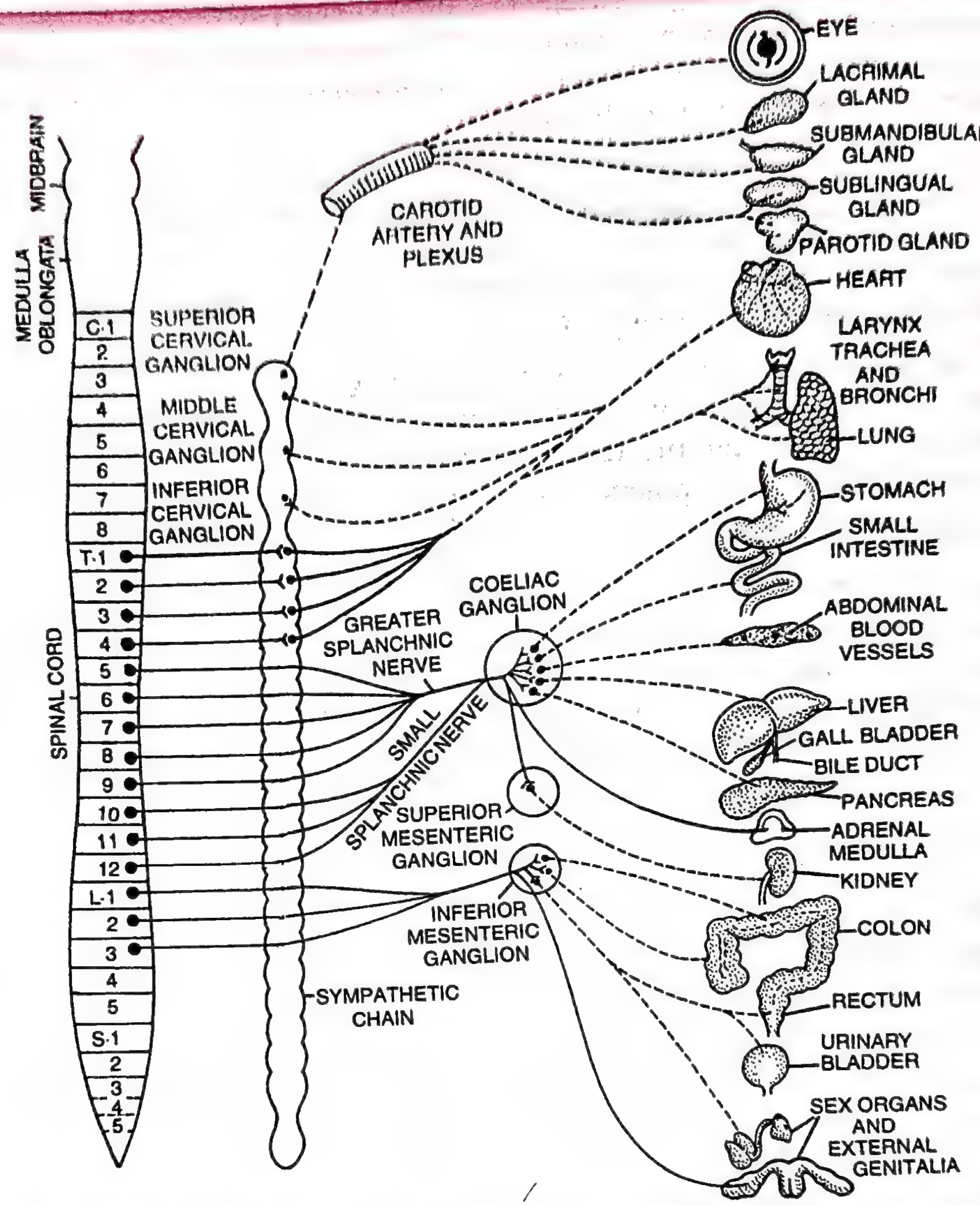


Fig. 21.15. Diagrammatic representation of sympathetic neural system. Preganglionic fibres are shown as solid lines and postganglionic fibres as dotted lines.

Parasympathetic Neural System

Parasympathetic nerural system (Fig. 21.16) consists of preganglionic fibres, parasympathetic ganglia and post-ganglionic fibres.

(i) **Preganglionic fibres.** These are the axons of the neurons situated in the midbrain, brainstem and sacral region of the spinal cord. The preganglionic fibres are found accompanying the cranial nerves and spinal nerves. Those preganglionic fibres which come from brain run along with the III, VII, IX and X cranial nerves while those preganglionic fibres coming from the spinal cord pass through 2, 3 and 4 sacral spinal nerves. Thus parasympathetic nerves arise from the **craniosacral** region of the neural system. The preganglionic fibres end in the parasympathetic ganglia.

(ii) **Parasympathetic ganglia.** These ganglia are located close to or within the viscera. They do not form a chain. The preganglionic fibres synapse with the neurons in the parasympathetic ganglia.

(iii) **Postganglionic fibres.** These are the axons of the neurons present in the parasympathetic ganglia. The postganglionic fibres innervate the smooth muscles and glands of the viscera.

Cholinergic neurons release the neurotransmitter **acetylcholine** (Ach). In the ANS, the cholinergic neurons include (a) all sympathetic and parasympathetic preganglionic neurons, (b) sympathetic postganlionic neurons that innervate most sweat glands and (c) all parasympathetic postganglionic neurons.

It is important to note that the preganglionic fibres of both sympathetic and parasympathetic neural system are **cholinergic.**

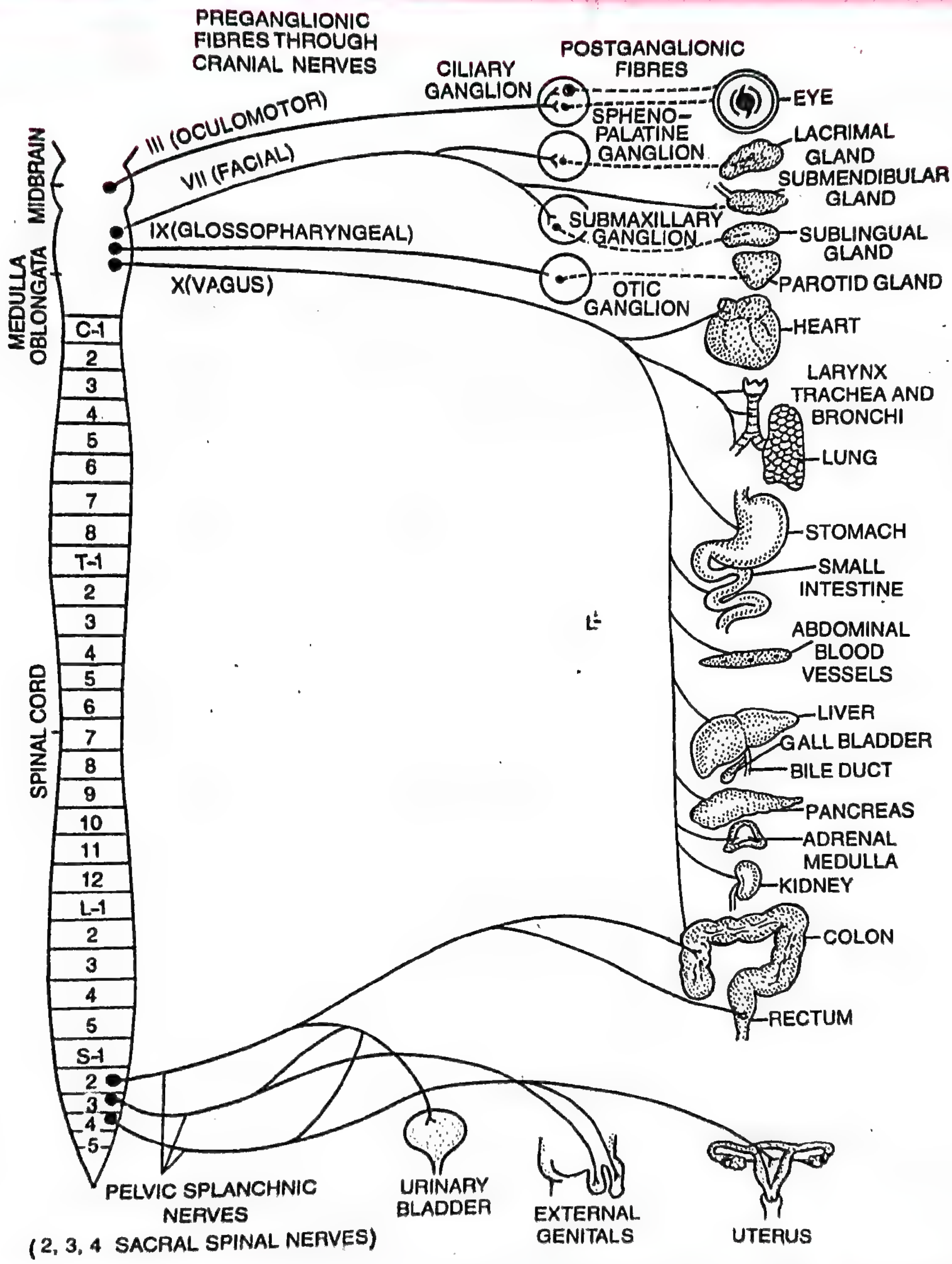


Fig. 21.16. Diagrammatic representation of parasympathetic neural system. Preganglionic fibres are shown as solid lines and postganglionic fibres as dotted lines.

Because the autonomic neural system innervates the viscera, it is also called the **visceral neural system**.

Differences between Adrenergic and Cholinergic Nerve Fibres	
Adrenergic Nerve Fibres	*Cholinergic Nerve Fibres*
1. These nerve fibres release neurotransmitters adrenaline and nor-adrenaline at their terminations.	1. These nerve fibres release neuro-transmitter acetylcholine at their terminations.
2. These are generally postganglionic sympathetic fibres.	2. These are generally all sympathetic and parasympathetic preganglionic nerve fibres and all parasympathetic post ganglionic nerve fibres.

Functions of Autonomic Neural System

The functions of sympathetic and parasympathetic neural systems are **antagonistic** to each other. Functions of both the systems are summarised in the following table.

Functions of autonomic neural system

Organ Innervated	*Function of Sympathetic Neural System*	*Function of Parasympathetic Neural System*
Heart	Accelerates heart beat	Slows heart beat
Arteries	Constricts arteries and raises blood pressure	Dilates arteries and lowers blood pressure
Digestive tract	Slows peristalsis, decreases activity	Speeds peristalsis, increases activity
Salivary glands	Inhibits secretion	Stimulates secretion
Gall Bladder	Relaxes	Contracts
Gastric glands	Inhibits secretion	Stimulates secretion
Pancreas	Inhibits secretion	Promotes secretion
Intestinal glands	Inhibits secretion	Stimulates secretion
Liver	Promotes sugar release; decreases bile production	Promotes glycogen formation; increases bile production
Urinary bladder	Relaxes bladder	Constricts bladder
Muscles in bronchi	Dilates passages, making breathing easier	Constricts passages
Muscles of iris	Dilates pupil	Constricts pupil
Muscles attached to hair (arrector pili muscle)	Causes erection of hair	Causes hair to lie flat
Sweat glands	Increases secretion	Decreases secretion

Some structures are supplied by sympathetic neural system alone, e.g., adrenal medulla, most arterioles, ureters, uterus, Fallopian tubes, seminal vesicles, etc. while there are *certain other structures having parasympathetic supply alone, e.g.*, oesophagus, gastric glands, pancreas including the islets of Langerhans, lacrimal glands, etc.

Differences between Sympathetic and Parasympathetic Neural Systems

Sympathetic Neural System	*Parasympathetic Neural System*
Anatomical Differences	
1. It has paired chains of ganglia and other visceral ganglia.	1. Chains of ganglia are absent. It has ganglia very close to the organ supplied.
2. Its preganglionic fibres originate from the spinal chord.	2. Its preganglionic fibres originate from the brain and spinal chord. Those preganglionic fibres which come from the brain run along with the III, VII, IX and X cranial nerves while those coming from spinal cord pass through 2, 3 and 4 sacral spinal nerves.
3. Its preganglionic fibres are shorter than the postganglionic fibres.	3. Its preganglionic fibres are much longer than the postganglionic fibres.
4. Each preganglionic fibre forms synapses with many post ganglionic fibres, so many organs are affected.	4. Each preganglionic fibre synapses with only a few post ganglionic fibres, and only one organ may be affected.
Physiological Differences	
5. Its postganglionic fibres are adrenergic *i.e.*, release the neurotransmitter noradrenaline (norepinephrine).	5. Its postganglionic fibres are cholinergic *i.e.*, release the neurotransmitter acetylcholine.
6. It stimulates the medulla of the adrenal glands to release epinephrine and norepinephrine. For other differences refer to functions of Autonomic Neural System.	6. None.

Reflex Action and Reflex Arc

Definition. It is a form of animal behaviour in which the stimulation of a sensory organ (receptor) results in the activity of some organ without the intervention of will. Actually it is a spontaneous automatic mechanical response to a stimulus without the will of the animal.

Mechanism of Reflex Action. If the reflex action is controlled by the spinal cord it is called **spinal reflex action** and if it is controlled by the brain it is known as **cerebral reflex action.** For a reflex action five things are normally essential : (i) receptor, (ii) sensory nerve fibres, (iii) a part of the central nervous system, (iv) motor nerve fibres and (v) effector organ such as muscles and glands. The sensory nerve fibres bring sensory impulses from the receptor organ to the central nervous system. The motor nerve fibres relay the motor impulses from the central nervous system to the effector organs. Thus an impulse travels a path during reflex action which is called **reflex arc.**

Examples of Reflex Action. 1. Closing of eyes when strong light is flashed across them.

2. Withdrawal of limbs when they are touched by hot things.

3. Watering of mouth on seeing favourite food.

4. Opening of mouth on hearing loud sound.

5. Withdrawal of limbs in a decapitated frog (whose head has been cut) when dipped in warm water or touched with an acid.

6. Typing, riding a bicycle, knitting etc.

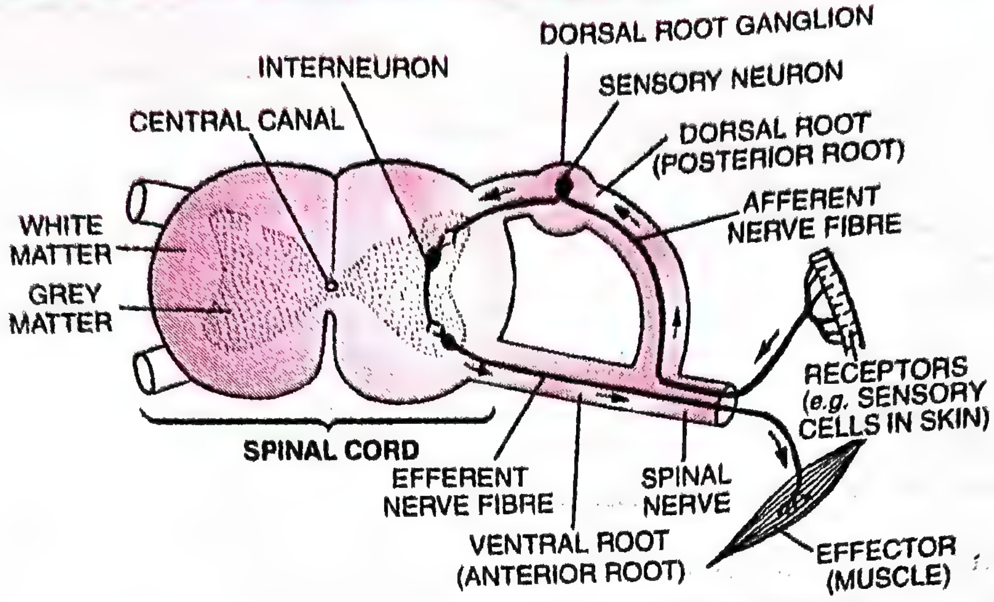


Fig. 21.17. Diagrammatic cross-section of the spinal cord to illustrate a typical vertebrate reflex arc. The arrows indicate the direction in which impulses are transmitted.

Although animal cannot have any choice in the above mentioned examples but in some of these reactions, the animal may have some knowledge. But there are many examples of reflex actions in which the animal does not have any knowledge of the reflex action. Examples are given below.

1. Discharge of bile from the gall bladder while the food passes from the opening of the bile duct.
2. Peristalsis of the alimentary canal.
3. Beating of heart.
4. Secretions of glands.

Importance of Reflex Action. (i) It is an important activity for the survival of the animal.

(ii) It relieves the brain from too much strain.

(iii) The responses of reflex action immediately protect the animal from harmful situations.

Reflexes

All the reflex activities of an organism can be broadly divided into (i) **unconditioned reflexes** and (ii) **conditioned reflexes.**

Unconditioned Reflexes are inborn reflexes and are transmitted through heredity. They are also called inborn or inherited reflexes, *e.g.,* Breast feeding and swallowing in newly born babies and blinking of eyes are the examples of unconditioned reflexes.

Conditioned Reflexes (CR). Conditioned reflexes are acquired reflexes during the life time of an individual. They are absolutely an individual entity and are, therefore, not constant, *viz.,* they may disappear and reappear again.

Ivan Pavlov, a Russian physiologist discovered for the first time the existence of conditioned reflexes and, therefore, he is called the **father of conditioned reflexes.**

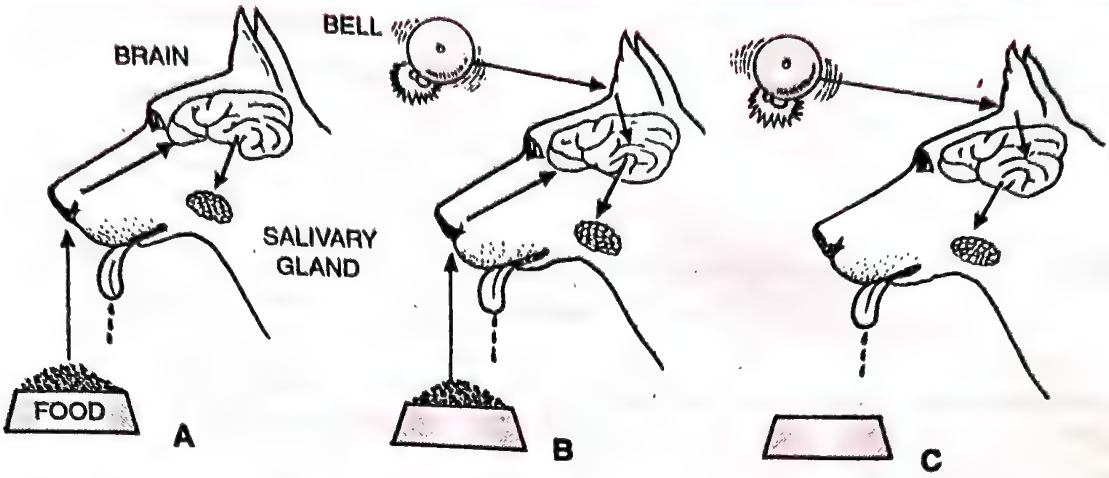


Fig. 21.18. The training procedure used by Ivan Pavlov in his studies of classical conditioning. (a) Prior to training, the presence of food causes a reflex action; the brain receives sensory information indicating that food is present and stimulates the salivary glands. (b) During training, a bell is sounded just before food is presented; these two stimuli eventually become associated in the dog's brain. (c) After training, the sound of bell alone causes the dog to salivate.

Characteristics of conditioned reflexes. (i) They are acquired in life.

(ii) They depend on previous experience.

(iii) They can be established or abolished.

(iv) They are not transmitted by heredity.

(v) Cortical and subcortical centres are responsible for them.

Experiments conducted by Pavlov. Pavlov (1906) had carried experiments with a dog. He rung a bell every time just before the food was placed in the dog's mouth. Gradually the dog learnt to associate the bell with food. The dog would salivate when the bell was rung even though no food was placed in its mouth. Pavlov called food, **unconditioned stimulus**, salivation in response to food an **unconditioned response**, sound of the bell the **conditioned stimulus** and salivation in response to bell the **conditioned response.**

Mechanism of conditioned reflexes. The reflex arc of a conditioned reflex includes the following parts. (i) Receptors which perceive the conditioned stimulus. (ii) A sensory nerve. (iii) An area in the cerebral cortex which perceives the conditioned stimulus. (iv) Another area in the cortex which is connected with the centre of the unconditioned reflex. (v) The motor nerve and (vi) the effector organ which responds accordingly.

Functions of conditioned reflexes. (i) Most of our habits are conditioned reflexes. Hence, it is of immense personal and social importance. (ii) They play an important part in physiology of learning. (iii) They also help animals to eliminate harmful influences, etc. (iv) They ensure adaptations of the organisms to the external environment in the course of its life experience and are essential for its better orientation in changing conditions.

Differences between Unconditioned Reflexes and Conditioned Reflexes

Unconditioned Reflexes	*Conditioned Reflexes*
1. They are inborn reflexes and transmitted through heredity.	1. They are acquired after birth. It means they are adopted during the course of life time.

2. Learning does not form the basis of unconditioned reflexes.	2. Learning forms the basis of conditioned reflexes.
3. Breast feeding and swallowing in newly born babies and blinking of eyes are examples of these reflexes.	3. Withdrawal of limb when it is touched by hot things and typing, riding a bicycle, knitting, etc. are examples of these reflexes.

- **Nerve Termination.** Nerve fibres terminate in three ways.

(i) The axon of one neuron ends on the dendrites of the next neuron. Such a junction is called **synapse.**

(ii) The axon of a neuron terminates on either a muscle fibre or a gland cell. When it ends on a muscle fibre, it forms the neuromotor junction. The contact between a neuron and glandular cells is called neuroglandular junction.

(iii) Many nerve fibres, for example in the skin, divide into fine branches known as the **sensory nerve endings.**

- **Main Properties of Neural Tissue.** The neural tissue has two outstanding properties : excitability and conductivity.

1. **Excitability.** It is the ability of the nerve cells and fibres to enter into an active state called the **state of excitation** in response to a stimulus. Excitation arises at the receptors on account of various stimuli such as light, temperature, chemical, electrical or pressure which constantly act on the organisms.

2. **Conductivity.** The excitation does not remain at the site of its origin. It is transmitted along nerve fibres. The transmission of excitation in a particular direction is called conductivity.

- **Stimulus.** A stimulus is sudden change in the environment (external or internal) which is strong enough to excite the nerve or muscle or organism as a whole. If the stimulus is capable to excite a given tissue, it is called **threshold stimulus** (adequate stimulus). If the stimulus is not capable to excite any response, it is called **subthreshold stimulus** (inadequate stimulus).

- **Summation.** As stated above, a subthreshold stimulus is unable to generate a nerve impulse. A series of subthreshold stimuli applied to a nerve fibre may succeed in initiating an impulse. This additive effect of several subthreshold stimuli is called **summation.**

- **All-or-none Principle.** It states that a neuron either conducts or does not conduct an impulse. If it conducts an impulse it is always of maximum size. Therefore, according to the all-or-none principle, a neuron can be thought of as being either "on" or "off".

- **Sodium-Potassium Pump.** The process of expelling out sodium ions and drawing in potassium ions against concentration gradient and electrochemical gradient is called **Sodium Potassium pump.** Thus it transports sodium from inside the cell to outside and potassium from outside into the cell by **active transport** in which a considerable amount of energy (ATP) is spent. It operates with the help of **Na^+, K^+** and **ATPase enzyme** located in the cell membrane. This pump is present in all the cells of the body.

The result of sodium-potassium exchange pump is that there is a difference in charge on either side of the membrane—positive outside and negative inside. This difference in charge on either side of the membrane of a resting neuron is the resting membrane potential and such a membrane is said to be polarized (resting potential).

Nerve Impulse

A nerve impulse may be defined as wave of depolarization of the membrane of the nerve cell. The nerve impulse travels along a neuron or across a synapse (junction), between one neuron and another, or between a neuron and an effector, such as a muscle or gland.

Transmission of Nerve Impulse

The nerve cells remain bathed in the **extracellular fluid** (ECF) or **interstitial fluid** containing a large amount of sodium chloride and bicarbonates. In addition, it contains nutrients and oxygen for supplying to the cell and carbon dioxide and other metabolic wastes released into it by the body cells. However, the **intracellular fluid** (cytoplasm of the neurons) contains a large amount of potassium and magnesium phosphates in addition to complex proteins and other organic molecules. Most of the solutes in extracellular fluid and the cytoplasm of the neuron are electrically charged particles or ions (positively charged **cations** or negatively charged **anions**).

Membrane or Ionic Theory of Nerve Impulse

This theory was proposed by English neurophysiologists Hodgkin and Huxley in the late 1930s. This theory states that electrical events in the nerve fibre are governed by the **differential permeability** of its membrane to sodium and potassium ions and that these permeabilities are regulated by the **electric field** across the membrane. The interaction of differential permeability and electric field makes a critical threshold of charge essential to excite the nerve fibre.

According to this theory, the process of nerve impulse conduction is divisible into two main phases— **resting membrane potential of nerve** and **action membrane potential of nerve**. Resting membrane potential has been described above. Action membrane potential is to be explained below under the heading depolarization.

Generation and Conduction of Nerve Impulse (Conduction of nerve impulse along the axon)

Polarisation (= Resting Potential). In a resting nerve fibre (a nerve fibre that is not conducting an impulse), the axoplasm (neuroplasm of axon) inside the axon contains high concentration of K^+ and negatively charged proteins and low concentration of Na^+. In contrast, the fluid outside axon contains a low concentration of K^+ and a high concentration of Na^+ and thus form a concentration gradient. These ionic gradients across the resting membrane are maintained by the active transport of ions by the sodium-potassium pump which transports 3 Na^+ outwards and 2 K^+ inwards (into the cell). As a result, the outer surface of the axonal membrane possesses a positive charge while its inner surface becomes negatively charged, and, therefore, is polarised. The electrical potential difference across the resting plasma membrane is called as the **resting potential**. The state of the resting membrane is called **polarised state.**

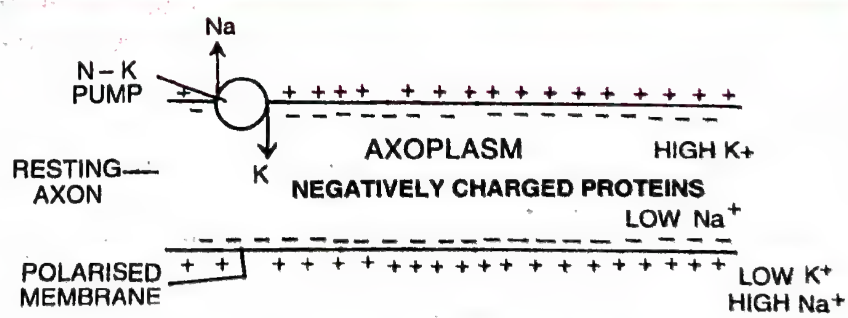


Fig. 21.19. Showing Resting Potential.

Thus to maintain resting potential sodium-potassium pump operates. In Na^+ — K^+ pump of active transport there is efflux of Na^+ and influx of K^+. It means Na^+ is out and K^+ is in.

Depolarization. When a stimulus of adequate strength (threshold stimulus) is applied at a site (Fig. 21.20, *e.g.*, point A) on the polarized membrane, the membrane at the site A becomes freely permeable to Na^+. This leads to a rapid influx of Na^+ followed by the reversal of the polarity at that site, *i.e.*, the outer surface of the membrane becomes negatively charged and the inner side becomes positively charged. The polarity of the membrane at the site A is thus reversed and hence depolarised. The electrical potential difference across the plasma membrane at the site A is called the **action potential**, which is in fact termed as a **nerve impulse**. At sites immediately ahead, the axon (*e.g.*, site B) membrane has a positive charge on the outer surface and a negative charge on its inner surface. As a result, a current flows on the inner surface from site A to site B. On the outer surface current flows from site B to site A (Fig. 21.20) to complete the circuit of current flow. Hence, the polarity at the site is reversed and an action potential is generated at site B. Thus, the **impulse** (action potential) generated at site A arrives at site B. The sequence is repeated along the length of the axon and consequently the impulse is conducted. The rise in the stimulus-induced permeability to Na^+ is extremely short lived. It is quickly followed by a rise in permeability to K^+. Within a fraction of a second, K^+ diffuse outside the membrane and restores the resting potential of the membrane at the site of excitation which is called **repolarization** and the fibre becomes once more responsive to further stimulation.

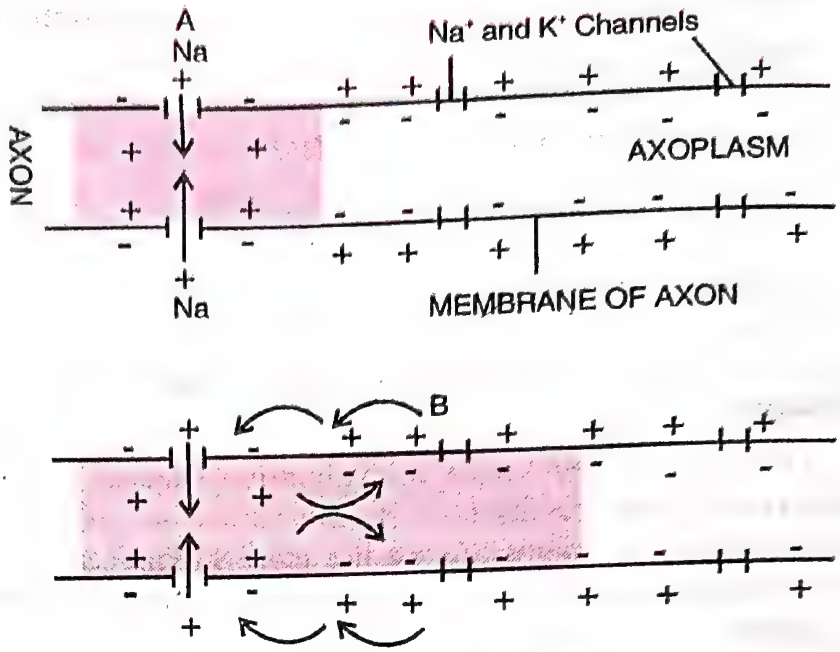


Fig. 21.20. Diagrammatic representation of impulse conduction through an axon (at points A and B)

Refractory Period. The repolarization period returns the cell to its resting potential. The neuron is now prepared to receive another stimulus and conduct it in the same manner. In fact until repolarization occurs neuron cannot conduct another impulse. It now becomes necessary to restore the normal resting membrane potential by expelling Na^+ and taking K^+ back in (the sodium potassium pump starts working). The time taken for this restoration is called **refractory period,** because during this the membrane is incapable of regenerating another impulse. One more benefit of refractory period is that impulses travel in the axon only in forward direction —unidirectional impulse conduction. The refractory period is very short, being only about one millisecond (1/1000 of a second). Thus a nerve fibre can transmit about 1000 impulses per second.

Speed of Nerve impulse. In man, the nerve fibres can transmit impulses at a maximum speed of about 130 metres per second, whereas in frog its speed is only about 30 metres per second.

Speed of Nerve Impulse (in metres per second) in some Animals

Vertebrates		Invertebrates		
Animal	*Regular Motor Nerve*	*Animal*	*Regular Motor Nerve*	*Giant Axon*
1. Fish	3–36	1. Sea anemone	0.1	—
2. Frog	7–30	2. Earthworm	0.6	30
3. Snake	10–35	3. Cockroach	2	10
4. Cat	30–120	4. Squid	4	35

Saltatory Conduction of Nerve Impulse

The properties of impulse conduction described so far apply to unmyelinated neurons. However, the myelin sheath of many axons in the body insulates those axons except at the nodes of Ranvier. When an impulse travels along a myelinated neuron, depolarization occurs only at the nodes. It leaps over the myelin sheath from one node to the next. This process, the **saltatory conduction**, gets its name from the root word saltere, which means to leap. Saltatory conduction accounts for the greater speed of an impulse travelling along a myelinated neuron than along a nonmyelinated one. Less energy is required for saltatory conduction than for conduction along a nonmyelinated neuron because smaller amounts of ATP are used to operate the sodium pump. It is upto 50 times faster than the nonmyelinated nerve fibre.

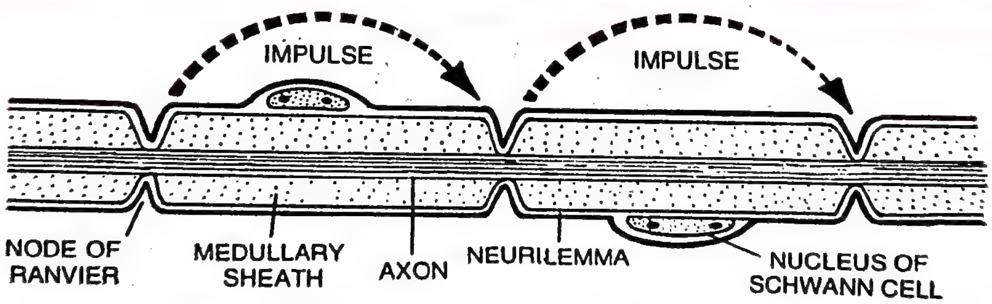


Fig. 21.21. Saltatory conduction of nerve impulse in a medullated nerve fibre.

The Synapse

The synapse is an area of functional contact between one neuron and another for the purpose of transferring information. Synapses are usually found between the fine terminal branches of the axon of one neuron and the dendrites or cell body of another. This type of neuron is called **axo-dendrite synapse**.

Sir Charles Sherrington (1861–1954) was the first person who used the term 'synapse' to the junctional points between two neurons.

Types of Synapse. On the basis of transmission of impulses, the synapse is of two types: Electrical synapse and chemical synapse. However, generally the term synapse refers to a chemical synapse.

Structure of Synapse. A typical (generalized synapse) consists of a bulbous expansion of a nerve terminal called a **pre-synaptic knob** lying close to the membrane of a dendrite. The cytoplasm of the synaptic knob contains mitochondria, smooth endoplasmic reticulum,

microfilaments and numerous **synaptic vesicles**. Each vesicle contains **neurotransmitter** (chemical substance) responsible for the transmission of the nerve impulse across the synapse. The membrane of the synaptic knob nearest the synapse is thickened and forms the **presynaptic membrane.** The membrane of the dendrite is also thickened and is called the **postsynaptic membrane.** These membranes are separated by a gap, the **synaptic cleft.** The post synaptic membrane contains large protein molecules which act as **receptor sites** for neurotransmitter and numerous **channels** and **pores.**

The two main neurotransmitters in vertebrate nervous system are **acetylcholine** (ACh) and **noradrenaline** although other neurotransmitters also exist.

Acetylcholine (**ACh**) was the first neurotransmitter to be isolated and obtained by **Otto Loewi** in 1920 from the endings of parasympathetic neurons of the vagus nerve in frog heart. Neurons releasing acetylcholine are described as **cholinergic neurons** and those releasing noradrenaline are described as **adrenergic neurons.**

Transmission of Impulses

1. **Transmission of Nerve Impulses at an Electrical Synapse.** At electrical synapse there is continuity between the presynaptic and postsynaptic neurons. The continuity is provided by the **gap junction** between the two neurons. The gap junctions are small protein tubular structures that allow free movement of ions between the two neurons. Because of this, the action potential reaching the presynaptic terminal produces potential change in the post-synaptic neuron. In electrical synapse there is minimal synaptic delay because of the direct flow of electrical current from one neuron into the other through gap junction. Thus impulse transmission across an electrical synapse is always faster than that across a chemical synapse. At an electrical synapse, the transfer of an impulse occurs by purely electrical means without involving any chemical (neurotransmitter). However, electrical synapses are relatively rare. It is found in the cardiac muscle fibres, smooth muscle fibres of intestine and the epithelial cells of lens. Most impulse transmission across the synapse between neurons takes place at the chemical synapses.

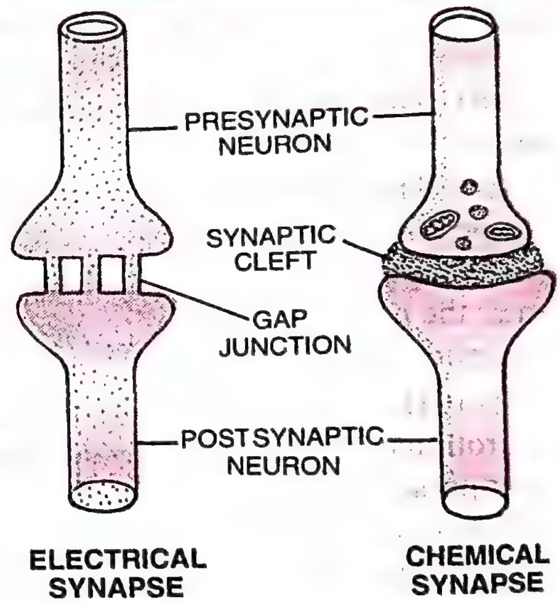


Fig. 21.22. Electrical and chemical synapses.

2. **Transmission of Nerve Impulse at a Chemical Synapse.** The process of chemical transmission across synapses was discovered by **Henry Dale** (1936). The physiological importance of synapse for the transmission of nerve impulses was established by **McLennan** in 1963.

A brief description of the mechanism of synaptic transmission is given below :

(i) When an impulse arrives at a presynaptic knob, calcium ions from the synaptic cleft enter the cytoplasm of the presynaptic knob.

(ii) The calcium ions cause the movement of the synaptic vesicles to the surface of the knob. The synaptic vesicles are fused with the presynaptic membrane and get ruptured (**exocytosis**) to discharge their contents (neurotransmitter) into the synaptic cleft.

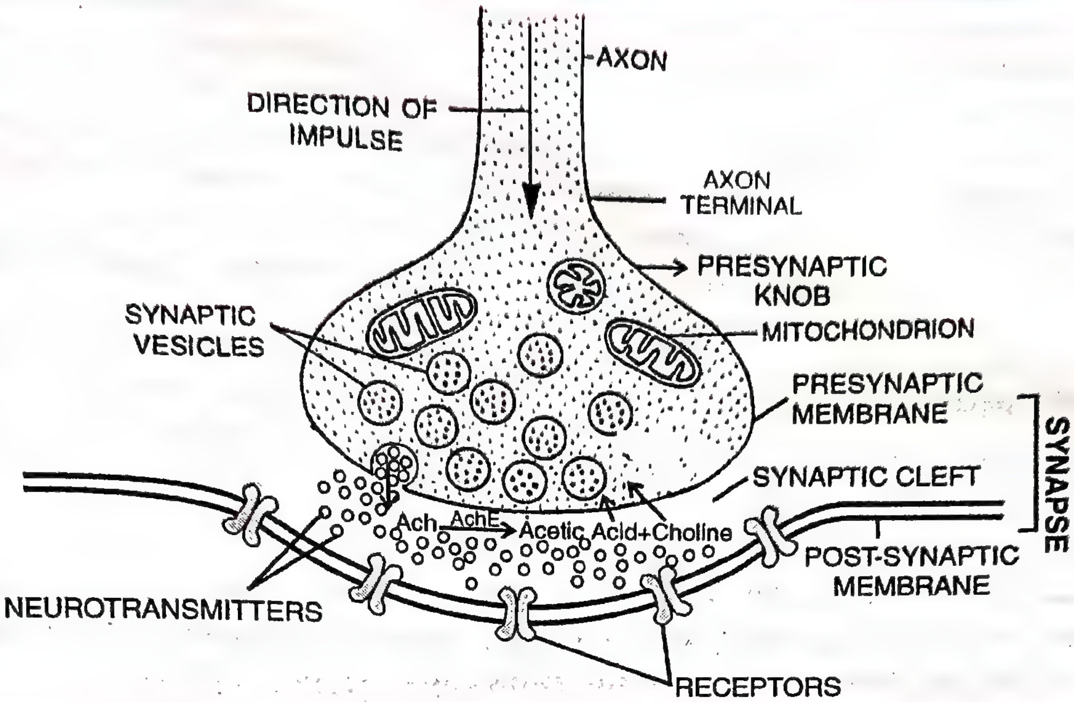


Fig. 21.23. Transmission of nerve impulse at a chemical synapse.

(iii) The synaptic vesicles then return to the cytoplasm of the synaptic knob where they are refilled with neurotransmitter.

(iv) The neurotransmitter of the synaptic cleft binds with protein receptor molecules on the post synaptic membrane. This binding action changes the membrane potential of the postsynaptic membrane, opening channels in the membrane and allowing sodium ions to enter the cell. This causes the **depolarization** and generation of **action potential** in the post-synaptic membrane. Thus the impulse is transferred to the next neuron.

(v) Having produced a change in the permeability of the postsynaptic membrane the neurotransmitter is immediately lost from the synaptic cleft. In the case of **cholinergic synapses,** acetylcholine (ACh) is hydrolysed by an enzyme **acetylcholinesterase** (AChE) which is present in high concentration at the synapse.

(vi) The products of the hydrolysis are **acetic acid** and **choline** which are reabsorbed into the synaptic knob where they are resynthesized into acetylcholine, using energy from ATP.

Neurotransmitters

As explained in the discussion of synapses, neurotransmitters are chemicals released from a presynaptic neuron that interact with specific receptor sites of a postsynaptic neuron. At least thirty chemicals thought to have the capacity to act as neurotransmitters, have been discovered, most of them in brain tissue, and more are likely to be found. Some of these neurotransmitters are discussed here.

Acetylcholine. The neurotransmitter **acetylcholine** is released at all neuromuscular junctions between motor neurons and skeletal muscle cells, at all synapses between preganglionic and postganglionic in the autonomic neural system, and at certain synapses between neurons in the central neural system.

The enzyme **acetylcholinesterase** is present on the membrane of the muscle cell or the postsynaptic neuron, where it breaks down acetylcholine into acetate and choline and terminates the action of the transmitter.

Norepinephrine. Another transmitter, **norepinephrine** (formerly called noradrenalin) is secreted by some neurons of the sympathetic neural system and also by some neurons of the central neural system. Norepinephrine is usually inactivated by the action of an enzyme **monoamine oxidase.**

Gamma amino-butyric acid (GABA). Gamma amino-butyric acid is released by synaptic knobs of the fibres of some interneurons in central neural system. It inhibits postsynaptic regeneration of action potential, hence it is called inhibitory neurotransmitter.

Other neurotransmitters are **dopamine** (DA), **serotonin, glycine, histamine, glutamic acid, aspirate, substrate P** and **nitric oxide (NO).**

Some Diseases of Neural System

1. **Poliomyelitis.** Poliomyelitis is an acute viral infection that destroys the cell bodies of motor neurons in the anterior horn of the spinal cord.

2. **Meningitis.** Meningitis, an inflammation of the meninges, is usually caused by an infectious organism. Several kinds of bacteria and viruses can infect the meninges.

3. **Neuritis.** More of a symptom than a specific disease, neuritis is a general term for disturbances of the peripheral neural system. Either sensory or motor fibres or both may be damaged.

4. **Multiple sclerosis.** Multiple sclerosis is a progressive degenerative disease of central neural system, so named because of the many sites in which hardened (or sclerotic) tissue has replaced the normal myelin sheaths of neurons.

5. **Sciatica.** It is an irritation or neuritis of the sciatic nerve. In fact *it is pain along the sciatic nerve*. The most common cause of sciatica is a "slipped" intervertebral disc. A disc in the lumbar area herniates or protrudes from the vertebral column. The central part of the disc may be pushed out through the peripheral fibrous part, causing pressure to be placed on the sciatic nerve. Other causes of sciatic include osteoarthritis and pregnancy, if the weight and position of foetus creates pressure on the sciatic nerve.

6. **Neuralgia.** Neuralgia is pain in a circumscribed area innervated by a sensory nerve of the peripheral neural system. It is often impossible to determine the case of the pain and difficult to relieve it.

7. **Parkinson's Disease. Cause.** It is caused by the destruction of the neurons of basal ganglia that produce the neurotransmitter dopamine. Thus dopamine is reduced in the brain. **Symptoms.** Symptoms include tremors and shakes in the limbs, a slowing of voluntary movements and feeling of depression. **Treatment.** It is treated by dopamine. The drug Exelon, prescribed to restore memory in Alzheimer's patients, may also offer some help for people who develop dementia from Parkinson's disease. One of the examples of this disease is the great boxer Mohammed Ali.

8. **Wilson's Disease.** Along with all symptoms of Parkinson's disease, there is degeneration of liver tissues also. The degeneration changes in liver and brain are due to disturbed copper metabolism. Wilson's disease is due to damage of the lenticular nucleus (a part of basal ganglia).

9. **Alzheimer's Disease (AD). Causes.** It is caused due to destruction of vast numbers of neurons in the hippocampus (a part of brain). Evidence suggests that it is due to a combination of genetic factors, environmental or lifestyle factors and the ageing process. There is loss of neurotransmitter acetylcholine. **Symptoms.** Individuals with AD initially have trouble remembering recent events. In the later stages, the patients may fail to

recognise their spouse or children. The disease is due to dementia (progressive loss of memory). **Treatment**. Drugs that inhibits acetyl cholinesterase (AChE), the enzyme that inactivates acetylcholine (ACh), improve alertness. **Tacrine**, the first anticholinesterase inhibitor approved for treatment of AD in the United States, has significant side effects. **Donepezil**, approved in 1998, is less toxic to the liver. Some evidence suggests that vitamin E (an antioxidant), oestrogen and ubuprofen may have beneficial effects in AD patients. Former USA President Ronald Reagan was suffering from Alzeheimer's disease.

10. **Schizophrenia. Causes.** (i) **Genetic factors.** It tends to run in some families. (ii) **Brain dysfunction.** Some findings indicate that some ventricles of the brain are larger in schizophrenics than in other persons and this increased size may produce abnormalities in the cerebral cortex. (iii) **Biochemical factors.** Drugs that increase dopamine activity in the brain tend to intensify schizophrenic symptoms. (iv) **Psychological factors.** The patients are more likely to suffer relapses when their families engage in harsh criticism ("you are nothing but trouble"), etc. **Symptoms.** This disorder is characterized by hallucinations (*e.g.*, seeing things or hearing voices that are not really there), delusions (beliefs with no basis in reality), disturbances in speech, disordered thought processes and disordered behaviours.

11. **Broca's aphasia.** There is an inability to speak in fluent sentences, although the person has no problem in understanding written or spoken words due to damage to the Broca's area in the frontal lobe of the cerebrum of the brain.

12. **Wernicke's aphasia.** There is difficulty in understanding spoken or written words and in putting words into meaningful sentences as a result of injury to the Wernicke's area in the temporal lobe of the cerebrum of the brain.

13. **Amnesia as a Result of Korsakoff's Syndrome.** Individuals who consume large amounts of alcohol for many years develop this illness. Symptoms of Korsakoff's syndrome include sensory and motor problems as well as heart, liver and GIT disorders and also amnersia (loss of memory). It is due to extensive damage to the portions of the thalamus and hypothalamus of the brain.

14. **Myelodysplasia.** It is the abnormality in the development of the spinal cord.

15. **Tabes Dorsalis.** This is a slowly progressive nervous disorder affecting both the motor and sensory functions of the spinal cord.

16. **Syringomyelia.** The presence of fluid filled cavities in the spinal cord is known as syringomyelia.

Receptors

Receptor is a sensory organ or a cell which receives stimuli (changes in the environment) from outside or inside the animal and passes impulses to the nervous system. The receptors are always connected with the central nervous system by means of sensory nerve fibres. The animal may make necessary adaptations through motor nerve fibres. It is important to note that nervous system cannot operate in the absence of receptors and in the same manner receptors cannot function without nervous system.

Types of Receptors

Receptors may be classified according to the type of stimuli they receive.

1. **Mechanoreceptors**. Respond to mechanical changes. They are of the following types:

(i) **Tangoreceptors**. Respond to touch and pressure *e.g.*, Merkel's discs, Meissner's

corpuscles and root hair plexus respond to touch. Pacinian corpuscles respond to strong pressure.

Baroreceptors (pressure-receptors) are sensory nerve endings in the wall of the atrium of the heart, vena cava, aortic arch and carotid sinuses. They are sensitive to stretching of the wall resulting from increased pressure from within.

(ii) **Algesireceptors**. Respond to pain, *e.g.*, Free nerve endings.

(iii) **Statoreceptors**. Respond to acceleration and gravity, *e.g.*, Hair cells in cristae and maculae of internal ear (membranous labyrinth).

(iv) **Phonoreceptors**. Respond to air borne sound waves, *e.g.*, hair cells in organ of Corti of internal ear (membranous labyrinth).

2. **Thermoreceptors**. Respond to temperature. They are of two types:

(i) **Caloreceptors**. Respond to heat, *e.g.*, Ruffini's corpuscles.

(ii) **Frigidoreceptors**. Respond to cold, *e.g.*, Krause's corpuscles.

3. **Chemoreceptors**. Respond to chemicals. They are of two types:

(i) **Gustatoreceptors**. Respond to taste, *e.g.*, Taste buds.

(ii) **Olfactoreceptors**. Respond to smell, *e.g.*, olfactory epithelium.

4. **Photoreceptors**. Respond to light, *e.g.*, rods and cones of retina of vertebrate eyes and ommatidia of compound eyes in arthropods.

5. **Nociceptors** (*noci*–harm). They respond to potentially damaging stimuli that result in pain.

Over stimulation of any receptor is painful and virtually all receptor types function as nociceptors at one time or another. For example, searing heat, extreme cold, excessive pressure and chemicals released at sites of inflammation are all interpreted as painful.

Organs of Sight (Eyes)

These are located in **eye orbits** formed by the skull bones.

Structure of Human Eye

The eye is a hollow, spherical structure measuring about 2.5 cm in diameter. Its wall is composed of three coats:

1. The outer fibrous coat— sclera, cornea.
2. The middle vascular coat— choroid, ciliary body, iris.
3. The inner nervous coat— retina.

1. **Fibrous Coat.** It is divided into the sclera and the cornea.

(i) **Sclera**. It covers most of the eye ball. The sclera or white of the eye contains many collagen fibres. It protects and maintains shape of the eye ball.

(ii) **Cornea**. It is a transparent portion that forms the anterior one- sixth of the eyeball. The cornea admits and helps to focus light waves as they enter the eye. The cornea is **avascular** (*i.e.*, gets no blood supply). This part of eye absorbs oxygen from the air. The cornea was one of the first organs to be successfully transplanted because it lacks blood vessels.

*In proportion to body size deer presumably possesses largest eyes amongst vertebrates.

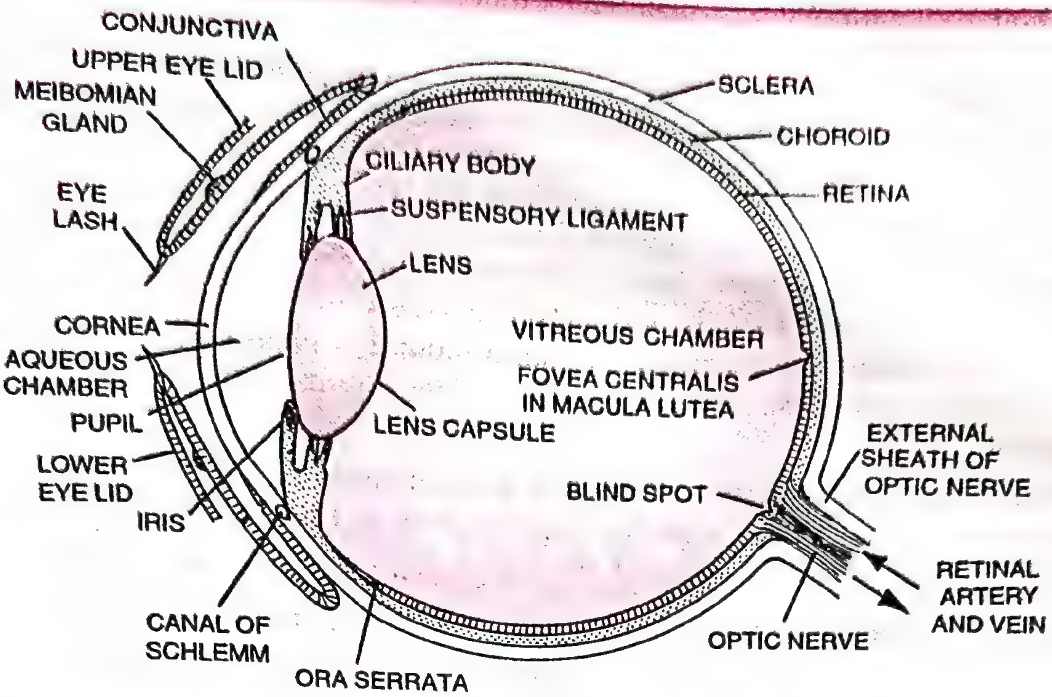


Fig. 21.24. V. S. Human Eye.

At the junction of the sclera and cornea there is a structure called the **canal of Schlemm.** From the anterior chamber the aqueous humour, which is continuously produced, is drained off into the canal of Schlemm and then into the blood.

2. **Vascular Coat**. It comprises the choroid, the ciliary body and the iris.

(i) **Choroid.** The choroid lies adjacent to the sclera and contains numerous blood vessels that supply nutrients and oxygen to the other tissues especially of retina. It also contains pigmented cells that absorb light and prevent it from being reflected within the eyeball.

(ii) **Ciliary body**. The ciliary body extends towards the inside of the eye from the choroid coat. It is composed of the **ciliary muscles** and the **ciliary processes**. The ciliary processes secrete aqueous humour. The ciliary muscles are smooth muscles and are of two types : **circular** and **meridional**. Attached to the ciliary body are the **suspensory ligaments,** which are in turn attached to the capsule that surrounds the lens of the eye. The capsule and ligaments, together with the ciliary body, hold the lens in place.

(iii) **Iris.** The iris is a circular muscular diaphragm containing the pigment giving eye its colour. It separates the aqueous humour region into

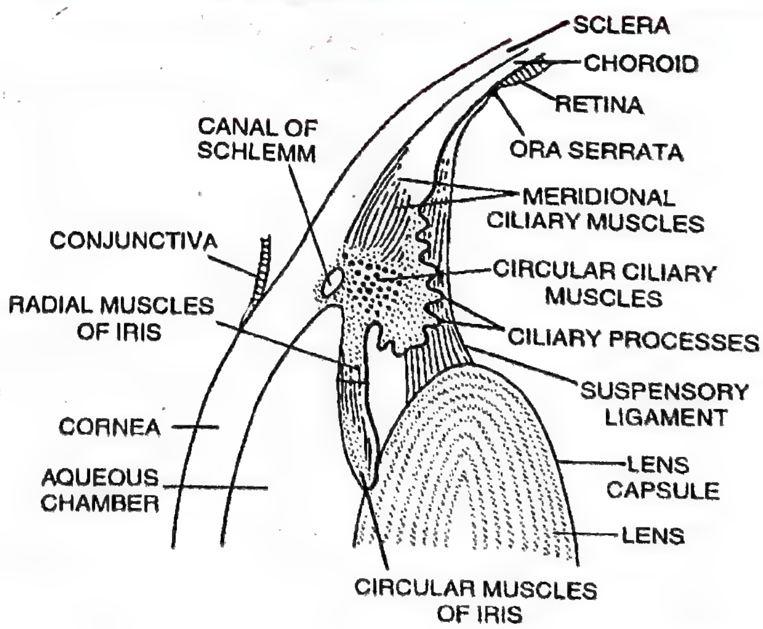


Fig. 21.25. Diagram showing ciliary and iris muscles.

anterior and posterior chambers. It extends from the ciliary body across the eyeball in front of the lens. It has an opening in the centre called the **pupil**. It contains two types of smooth muscles, **circular muscles** (sphincters) and **radial muscles** (dilators), of *ectodermal origin*. The iris controls the amount of light entering the eye by the radial muscles contracting in dim light and the circular muscles contracting in bright light. Both of these sets of muscles are under the control of the autonomic nervous system. Sympathetic stimulation causes the radial muscles to contract and the pupil to dilate, or get larger. Parasympathetic stimulation causes the circular muscles to contract and the pupil to constrict.

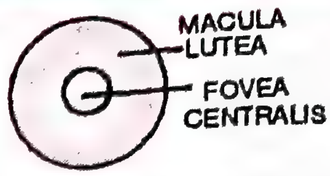


Fig. 21.26. Schematic representation of the position of fovea centralis.

3. **Neural Coat— The Retina.** The retina is the neural and sensory layer of the eye ball. Its external surface is in contact with the choroid and its internal surface with the vitreous humour. A small oval, yellowish area of the retina lying exactly opposite the centre of the

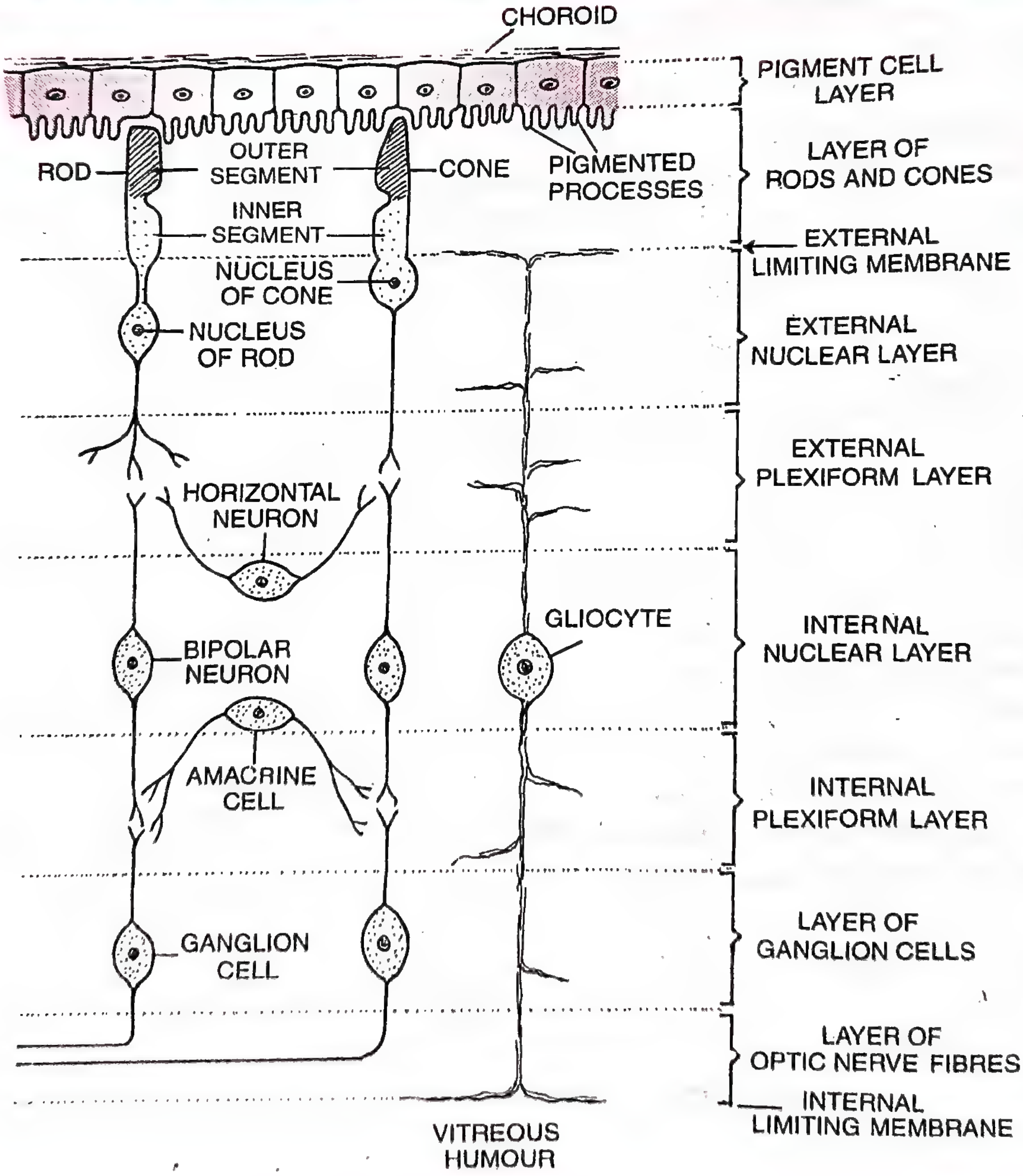


Fig. 21.27. Schematic diagram to show the layers of the retina and main structures therein.

cornea is named the **macula lutea** or **yellow spot** which has at its middle a shallow depression, the **fovea centralis.** *The fovea centralis has cone cells only.* It is devoid of rods and blood vessels. The fovea centralis is the place of most distinct vision. Here the nerve fibres from the light-sensitive cells leave the eyeball to form the optic nerve. An artery and a vein also pass through the optic disc. This area is called the blind spot because it is devoid of receptor cells. **Ora serrata** (= ora terminalis) is a special structure which demarcates the sensitive part of retina from its nonsensory part.

Beginning from the external surface (choroid side), the retina consists of the following layers.

(i) **Pigment Cell Layer.** This layer lies close to the choroid. It consists of a single layer of cells containing pigment. These pigment cells appear to be rectangular in vertical section, their width being greater than their height. The cells give rise to pigmented processes (projections), extending into the next layer.

(ii) **Layer of Rods and Cones.** The rods are processes of rod cells and cones are processes of cone cells. The total number of rods in the human retina has been estimated at 110 to 125 million and cones at 6.3 to 6.8 million (Osterberg 1935). The rods contain a photosensitive pigment called the **rhodopsin** (= visual purple). Rhodopsin is composed of **opsin** and **retinene.** The opsin is a protein and is called **scotopsin** in rhodopsin. The retinene is an aldehyde of vitamin A and is also called **retinal**. The rods mainly enable the animal to see in the darkness, therefore, rods are present in large number in nocturnal animals. The photosensitive pigment in the cones is of three types namely : **porpyrosin, iodopsin** and **cyanopsin** which give response to red, green and blue light respectively. The sensations of different colours are produced by various combinations of these three types of cones and their photopigments. When the three types of cones are stimulated equally, a sensation of white light is produced. The protein in cone pigment is called **photopsin**, which is different from scotopsin of rhodopsin.

(iii) **External Nuclear Layer.** This layer contains the cell bodies and nuclei of rod and cone cells.

(iv) **External Plexiform Layer** (= *Outer Synaptic zone*). This layer consists only of nerve fibres that form a plexus (network). The axons of rods and cones synapse here with dendrites of bipolar neurons. Processes of horizontal cells also take part in the formation of these synapses.

(v) **Internal Nuclear Layer.** This layer contains the cell bodies and nuclei of three types of neurons. (a) *Bipolar Neurons* (b) *Horizontal Neurons* and (c) *Amacrine cells.*

(vi) **Internal Plexiform Layer.** (= *Inner Synaptic Zone*). This layer consists of synapsing nerve fibres of bipolar neurons, ganglion cells and amacrine cells. This layer also contains some horizontally placed **internal plexiform cells** and also a few ganglion cells.

(vii) **Layer of Ganglion Cells.** This layer contains the cell bodies of ganglion cells. Axon of each ganglion cell gives rise to a fibre of the optic nerve.

(viii) **Layer of Optic Nerve Fibres.** This layer is made up of axons of ganglion cells that form the optic nerve. The optic nerves are connected with the brain.

The nerve fibres from all parts of the retina converge to leave through a **blind spot** (= Optic disc) which contains no rods and cones and, therefore, no image is formed at this spot.

Retinal Gliocytes (= Cells of Muller). In addition to **bipolar, horizontal neurons** and **amacrine cells,** the internal nuclear layer also contains the cell bodies of the **retinal gliocytes** (= cells of Muller). These cells form numerous protoplasmic processes that extend through

almost the whole thickness of the retina and form **external** and **internal limiting membranes.** The internal limiting membrane separates the retina from the vitreous humour. Retinal gliocytes support the neurons of the retina and may ensheath them. They also have nutritive function. Some astrocytes (other glial cells) are also present in between the retinal neurons.

Contents of the Eye Ball

(i) **The lens.** It is a transparent, biconvex, elastic structure that bends light waves as they pass through its surfaces. The lens separates the aqueous and vitreous humours. It is composed of epithelial cells that have large amounts of clear cytoplasm in the form of fibres. Its capsule is composed of layers of intercellular protein. The lens can change shape from moment to moment and, by doing so, focuses light waves into the retina from objects at different distances from the eye. The lens can also change shape from year to year, thereby accounting for changes in vision.

(ii) **Aqueous Humour.** The space between the cornea and the lens is called the **aqueous chamber** which contains a thin watery fluid called **aqueous humour.** The epithelium of the ciliary process continuously secretes a watery fluid, the aqueous humour. The aqueous humour helps to maintain the shape of the front part of the eye and provides nutrients to the lens and cornea. As stated earlier, the aqueous humour is continuously drained off into the canal of Schlemm and then into the blood. The pressure in the eye, called intraocular pressure is produced mainly by the aqueous humour.

(iii) **Vitreous Humour.** The space between the lens and retina is called the **vitreous chamber** which is filled with a transparent gel called the **vitreous humour.** It helps to maintain the shape of the eyeball and also contributes to intraocular pressure (pressure inside the eyeball). Unlike the aqueous humour, the vitreous humour cannot be replaced in any significant quantity. Therefore, in puncture wounds of the eye it is important to prevent the escape of vitreous humour.

Differences between Aqueous Humour and Vitreous Humour

Aqueous Humour	*Vitreous Humour*
1. It is a watery fluid.	1. It is a jelly-like substance.
2. It is present between cornea and lens.	2. It is present in lens and retina.
3. It is continuously secreted by ciliary processes and drained out of the eye.	3. It is not replaced.
4. Obstruction in its flow may damage retina by increasing intraocular pressure and may cause glaucoma.	4. It does not flow.

Differences between Blind Spot and Yellow Spot

Blind spot	*Yellow spot (Macula lutea)*
1. Optic nerve arises from this spot.	1. It is yellowish area of the retina lying exactly opposite the centre of the cornea.
2. It does not have a shallow depression.	2. It has at its middle a shallow depression called fovea centralis.
3. No image is formed at blind spot.	3. Image is formed at yellow spot.

Differences between Blind Spot and Fovea Centralis	
Blind Spot	*Fovea Centralis*
1. Optic nerve fibres arise from it.	1. It is a shallow depression of the retina in the middle of the macula lutea (yellow spot).
2. There are no rods and cones.	2. It has cones only.
3. No image is formed at blind spot.	3. It is the place where most distinct image is formed.

Differences between Rods and Cones	
Rods	*Cones*
1. Rods are sensitive to dim light.	1. Cones are sensitive to bright light only.
2. These contain rhodopsin pigment formed from vitamin A.	2. These contain iodopsin pigment.
3. Rods do not help in seeing colours.	3. Cones help in seeing colours.

Differences between Iodopsin and Rhodopsin	
Iodopsin (Visual violet)	*Rhodopsin* (Visual purple)
1. It is found in cones.	1. It is present in rods.
2. It is sensitive to bright light and gives "day light" vision.	2. It is sensitive to dim light and gives "twilight" vision.
3. It gives colour vision.	3. It does not give colour vision.
4. Insufficient iodopsin results in colour-blindness.	4. Insufficient rhodopsin results in night-blindness which is due to vitamin A deficiency.

Extrinsic Eye Muscles and their Nerve Supply

There are six extrinsic muscles (Fig. 21.13) attached to the eyeball. Four of these muscles are **straight** and two are **oblique**. These muscles are **median rectus, lateral rectus, superior rectus, inferior rectus, superior oblique** and **inferior oblique**.The oculomotor (3rd cranial nerve) innervates the median rectus, superior rectus, inferior rectus and inferior oblique. The **trochlear** (4th cranial nerve) supplies the superior oblique. The **abducens** (6th cranial nerve) innervates the lateral rectus.

The Accessory Structures of the Eye

These include the eyebrows, the eyelids and eyelashes, the conjunctiva and the lacrimal apparatus.

1. **The Eyebrows.** These are two arched eminences of skin surmounting the supra-orbital margins of the frontal bone. Numerous hairs project obliquely from the surface of the skin. The function of the eyebrows is to protect the anterior aspect of the eyeball from sweat, dust and other foreign bodies.

2. **The Eyelids (Palpebrae) and Eyelashes.** The eyelids are two movable folds situated above and below the front of the eye. On their free edges, there are outgrowths of hairs—the eyelashes. The third eyelid is vestigial and is called **plica semilunaris** (nictitating membrane). The inner surface of each eyelid and parts of the eyeball are covered with mucous membrane, called the conjunctiva.

Glands of Zeis are modified sebaceous glands which are associated with the follicles of eye lashes. They open into the follicles of eye lashes. **Meibomian** or **tarsal glands** are also modified sebaceous glands (oil glands) which are present along the edges of the eyelids. They produce an oily secretion which serves to lubricate the corneal surface and hold a thin layer of tears over the cornea. **Glands of Moll** are modified sweat glands at the edge of the eye lid.

3. **Conjunctiva.** It is a transparent mucous membrane, which covers the internal palpebral surfaces, and folds on to the anterior sclera and cornea where it is continuous with the corneal epithelium. The conjunctiva helps to protect the eye ball and keeps it moist. It is this membrane that becomes inflamed in **conjunctivitis** or "pink eye".

4. **The Lacrimal Apparatus.** The lacrimal apparatus of each eye consists of a **lacrimal gland** and its numerous ducts, the **superior** and **inferior canaliculi,** a **lacrimal sac** and a **nasolacrimal duct.** The lacrimal gland is situated in the orbit on the superior, lateral surface of the eyeball. The lacrimal gland secretes **tears** which are composed of water, salts and bactericidal protein called **lysozyme.** The tears flow into the superior and inferior canaliculi, then to the lacrimal sac and through the nasolacrimal duct into the nasal cavity. The function of tears is to bathe the front of the eye, washing away any dust, grit and microorganisms. Lysozyme destroys microorganisms present on the front of the eyeball. In emotional states the secretion of tears may be increased and if the nasolacrimal duct cannot carry them all into the nasal cavity, they overflow. Gland cells in the conjunctiva also secrete a mucous substance that is a component of tears.

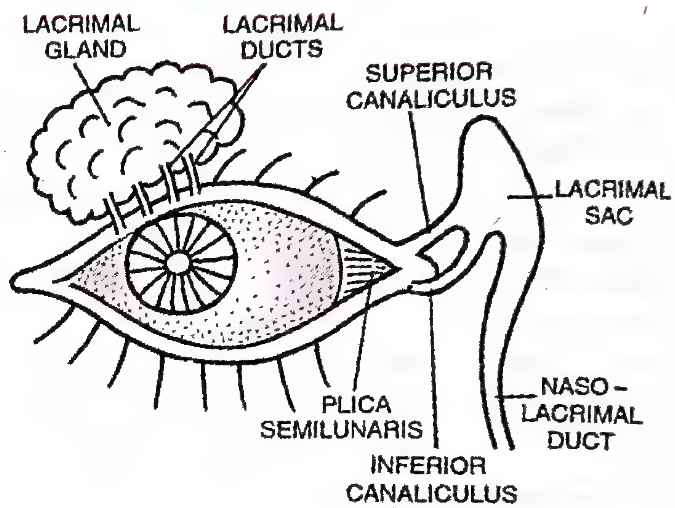


Fig. 21.28. Human lacrimal apparatus.

5. **Adipose Tissue** (fat). A layer of adipose tissue surrounds the eyeball in the orbit. It serves as a soft, shockproof pad.

Mechanism of Vision

The light rays pass through cornea, aqueous humour, lens and vitreous humour and focus on retina where they generate potentials (impulses) in rods and cones. As we know, human eyes have remarkable power of accommodation by changing the convexity of the lens. By the action of iris muscles the size of pupil can be increased or decreased. In bright

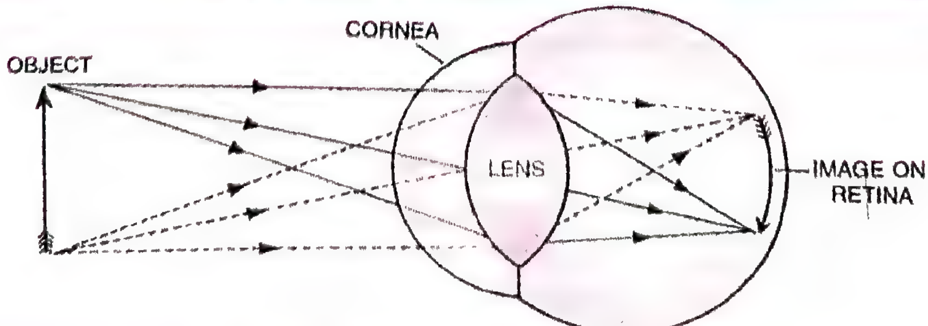


Fig. 21.29. Image formation on the retina.

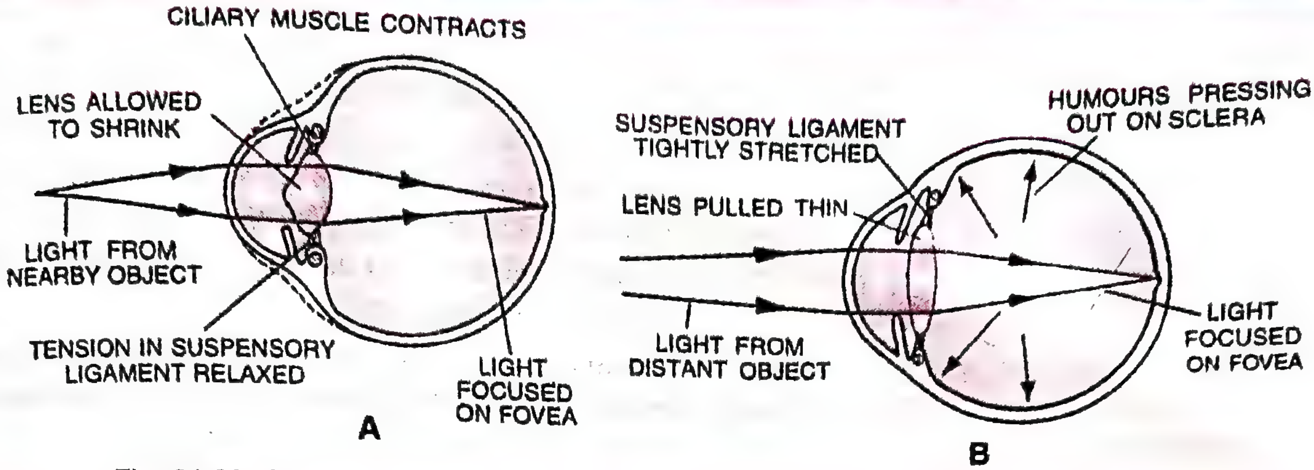


Fig. 21.30. A, Accomodation for near object; B, Accomodation for distant object.

light the pupil is constricted. In dim light it is dilated. Due to the action of the muscles of the ciliary body and the suspensory ligament, the focal length of the lens can be changed. Then the objects can be focussed in different intensity of light from varying distances. The photosensitive compounds (photopigments) in the human eyes are composed of **opsin** (a protein) and **retinal** (an aldehyde of vitamin A). Light induces dissociation of retinal from opsin which changes the structure of the opsin. Thus potential differences are generated in the photoreceptor cells. This causes action potentials in the ganglion cells through the bipolar cells. These action potentials (impulses) are transmitted by the optic nerves to the **visual cortex** area in the **occipital lobe** of the cerebral hemisphere of the brain where the neural impulses are analysed and erect image is recognised.

In the darkness, rhodopsin is resynthesized from opsin and retenene to restore the dark vision. It is called **dark adaptation**.

It is considered that there are three different kinds of cones, each of which contains a different light-sensitive **pigment**. (a) Cones that contain **erythrolable** are most sensitive to red light. (b) Cones that contain **chlorolable** are most sensitive to green light. (c) Cones that contain **cyanolable** are most sensitive to blue light. Combinations of these three colours of light produce all the colours human can see. This is in accordance with the **trichromacy theory**.

Binocular vision. When both the eyes can be focused simultaneously on a common object, as in human eyes, it is called binocular vision. It is just reverse to the **monocular vision**, as in many animals like **rabbit**, in which each eye focuses its own object and both the eyes cannot focus on one object.

Correspondence between Camera and Eye

Camera	Eye
1. Box	1. Sclera
2. Black inner paint	2. Choroid
3. Shutter	3. Eye lids
4. Diaphragm	4. Iris
5. Light hole	5. Pupil
6. Lens	6. Lens
7. Light Sensitive plate or film	7. Retina
8. Image small and inverted	8. Image small and inverted.

Organs of Hearing and Equilibrium

The organs of hearing and equilibrium are a pair of ears which are situated on the sides of the head.

Structure of Human Ear

Each ear consists of three portions: (i) External ear, (ii) Middle ear and (iii) Internal ear.

1. **External Ear.** It comprises a pinna, external auditory meatus (canal) & tympanic membrane.

(i) **Pinna.** The pinna is a projecting elastic cartilage covered with skin. Its most prominent outer ridge is called the **helix.** The **lobule** is the soft pliable part at its lower end composed of fibrous and adipose tissue richly supplied with blood capillaries. It is sensitive as well as effective in collecting sound waves.

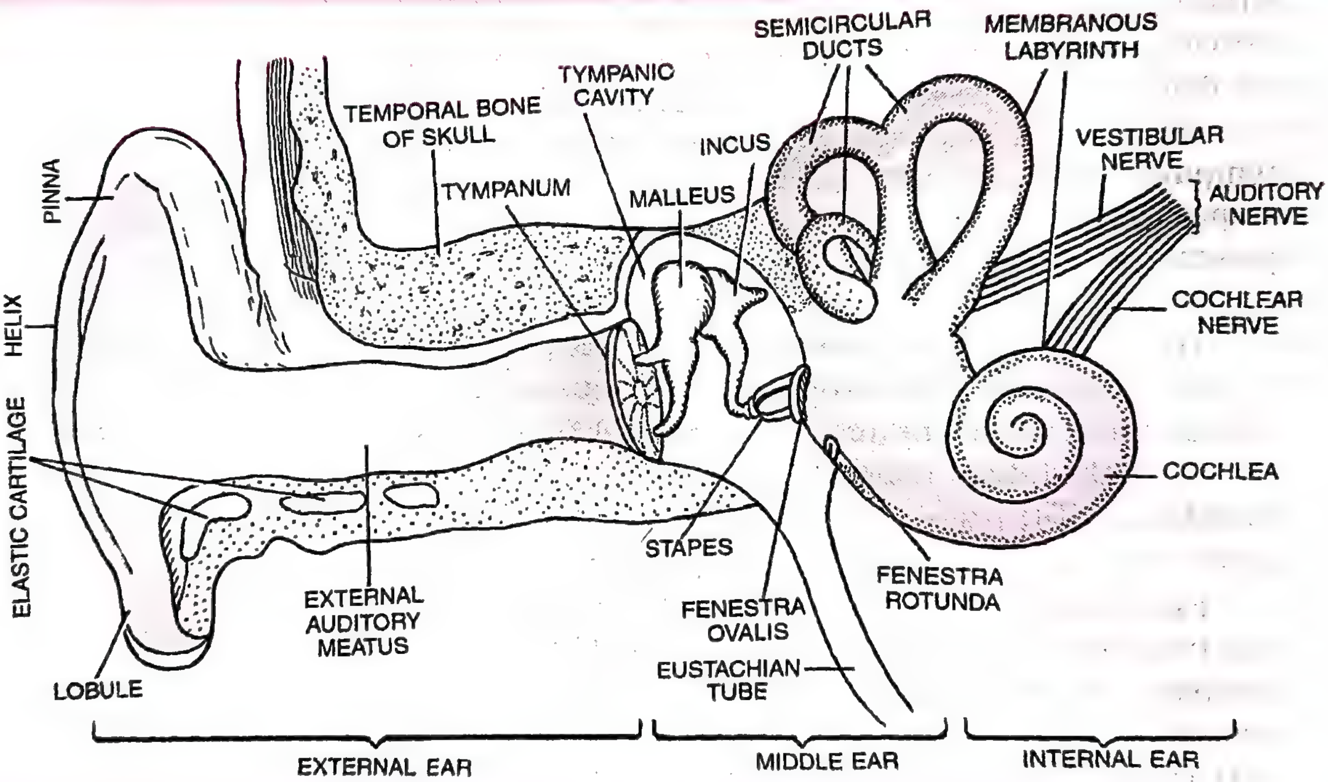


Fig. 21.31. The parts of human ear.

(ii) **External Auditory Meatus.** It is a tubular passage supported by cartilage in its exterior part and by bone in its inner part. The meatus (canal) is internally lined by hairy skin (stratified epithelium) and **ceruminous glands** (wax glands). The latter are modified sweat glands which secrete a waxy substance— the **cerumen** (ear wax) which prevents the foreign bodies entering the ear.

(iii) The **tympanic membrane** (tympanum) separates the tympanic cavity from the external auditory meatus. It is thin and semi-transparent, almost oval, though somewhat broader above than below. The central part of the tympanic membrane is called the **umbo.** The handle of the malleus is firmly attached to the membrane's internal surface.

Functions of External Ear. It directs sound waves towards the tympanic membrane. The sound waves produce pressure changes over the surface of the tympanic membrane. The cerumen (ear wax) prevents the entry of the foreign bodies into the ear.

2. **Middle Ear.** It includes the following :

(i) The **tympanic cavity,** filled with air is connected with the nasopharynx through the **Eustachian tube** (auditory tube), which serves to equalize the air pressure in the tympanic cavity with that on the outside.

(ii) There is a small flexible chain of three small bones called **ear ossicles**— the **malleus** (hammer shaped), the **incus** (anvil shaped) and the **stapes** (stirrup shaped). The malleus is attached to the tympanic membrane on one side and to the incus on the other side. The incus in turn is connected with the stapes, which is attached to the oval membrane covering the fenestra ovalis (oval window) of the inner ear. *Malleus is the largest ossicle, however, stapes is smallest ossicle. Stapes is also the smallest bone in the body.*

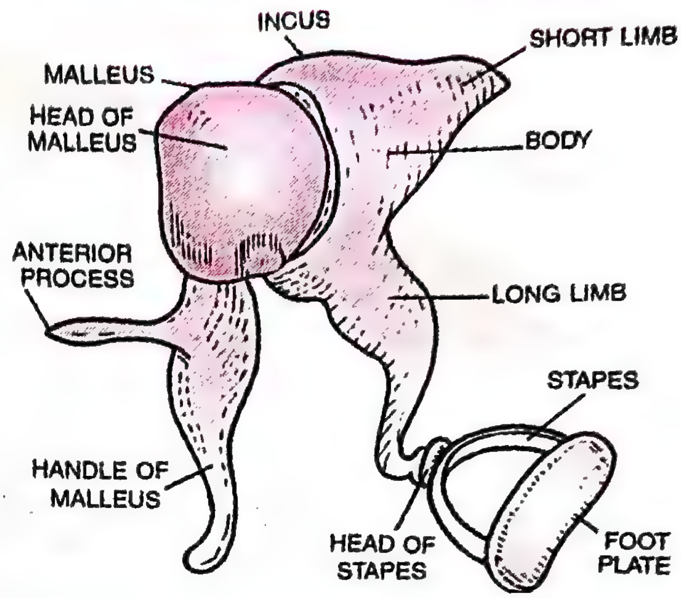


Fig. 21.32. Ear ossicles.

(iii) Two skeletal muscles, the **tensor tympani** attached to the malleus and the **stapedius** attached to the stapes, are also present in the middle ear. Stapedius is the smallest muscle in the body.

(iv) The middle ear is connected with the inner ear through two small openings closed by the membranes. These openings are (a) **fenestra ovalis** (oval window) as mentioned above and (b) **fenestra rotunda** (round window). The fenestra ovalis is covered by foot plate of the stapes. The fenestra rotunda is enclosed by a flexible **secondary tympanic membrane.** *The latter is responsible for equalizing the pressure on either side of the tympanic membrane* (tympanum).

Functions of Middle ear. (i) Due to the pressure changes produced by sound waves, the tympanic membrane vibrates, *i.e.,* it moves in and out of the middle ear. Thus the tympanic membrane acts as a resonator that reproduces the vibration of sound. (ii) It transmits sound waves from external to the internal ear through the chain of ear ossicles. (iii) The intensity of sound waves is increased about twenty times by the ear ossicles. It may be noted that the frequency of sound does not change. (iv) From the tympanic cavity extra sound is carried to the pharynx through Eustachian tube.

3. **Internal Ear.** There is a bony cavity on each side enclosed in the hard periotic bone which contains the **perilymph.** The later corresponds to the cerebrospinal fluid. A structure, the **membranous labyrinth** floats in the perilymph. The membranous labyrinth consists of three semicircular ducts, utricle, saccule, endolymphaticus and cochlea.

(i) **Semicircular Ducts.** There are present three semicircular ducts; the **anterior,** the **posterior** and the **lateral semicircular ducts.** They arise from the utricle. The anterior and posterior semicircular ducts arise from **crus commune.** Each semicircular duct is enlarged at one end to give rise to a small rounded **ampulla.** The anterior and lateral semicircular ducts bear ampullae at their anterior ends, while the posterior duct contains an ampulla at its posterior end. Each ampulla contains a sensory patch of cells, the **crista.** Each crista consists of two kinds of cells, the sensory and supporting cells. The sensory cells bear long sensory hairs at their free ends and nerve fibres at the other end. The sensory hairs are partly

embedded in a gelatinous mass, the **cupula.** The cristae are concerned with balance of the body.

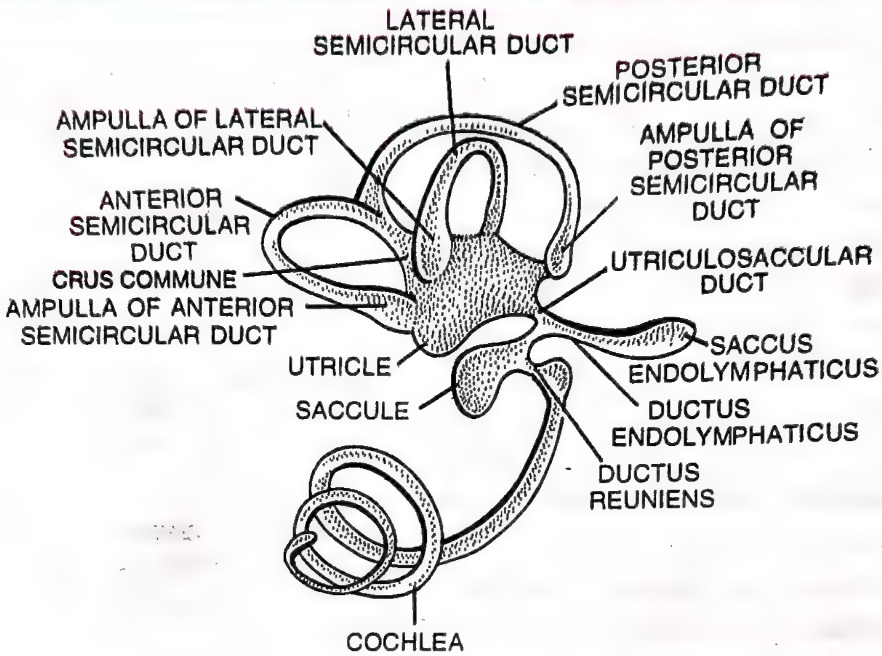


Fig. 21.33. Membranous labyrinth.

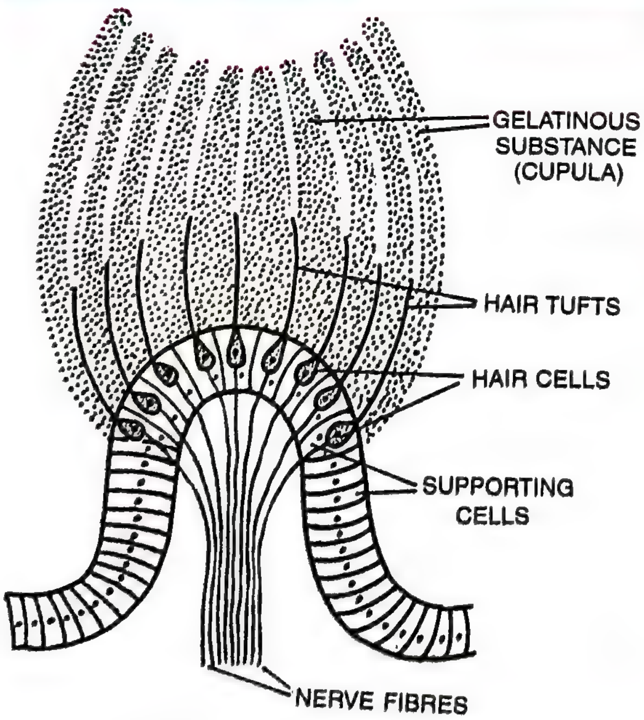


Fig. 21.34. Structure of crista.

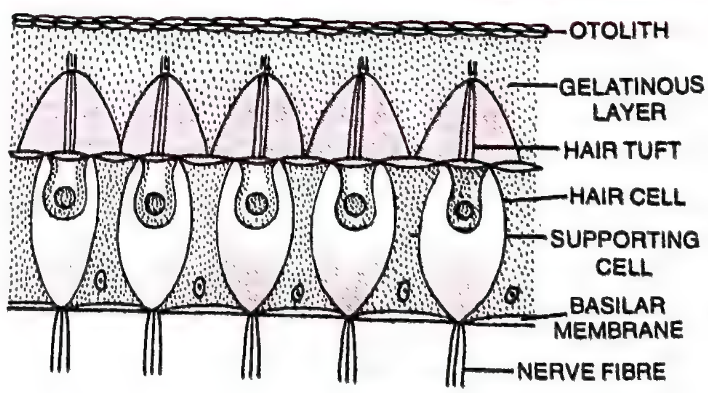


Fig. 21.35. Structure of macula.

(ii) **Utricle, Endolymphaticus and Saccule.** The utricle is a dorsally placed structure to which all the three semicircular ducts are connected. The saccule is a ventrally situated structure which is joined with the utricle by a narrow **utriculosaccular duct.** From this duct a long tube, the **ductus endolymphaticus** arises which ends blindly as the **saccus**

endolymphaticus. Both utricle and saccule contain sensory patches, the **maculae.** A macula comprises sensory and supporting cells similar to those of the crista. The hair are not actually motile and are embedded in a gelatinous membrane, the otolith **membrane** in which there are also found very small crystals of calcium carbonate, the **otolith**. The cristae and maculae are the receptors of balance.

Differences between Cristae and Maculae	
Cristae	*Maculae*
1. Cristae are present in ampullae of semicircular ducts. 2. These are three in number. 3. Each crista has gelatinous substance called cupula.	1. Maculae are present in utricle and saccule. 2. These are two in number. 3. Each macula contains calcarious ear stones called otolith.

Both cristae and maculae are concerned with balance.

(iii) **Cochlea.** It is the main hearing organ which is connected with saccule by a short **ductus reuniens** leading from the saccule. It is spirally coiled that resembles a snail shell in appearance. It tapers from a broad base to an almost pointed apex. Internally it consists of three fluid filled chambers or canals, the upper **scala vestibuli,** lower **scala tympani,** and the middle **scala media** (cochlear duct). Both scala vestibuli and scala tympani are filled with **perilymph.** However scala media is filled with **endolymph.** Both the scala vestibuli and scala tympani are connected with each other at the apex of the cochlea by a small canal, the **helicotrema.** It is important to mention that near the base of the scala vestibuli the wall of the membranous labyrinth comes in contact with the fenestra ovalis, while at the lower end of the scala tympani lies the fenestra rotunda.

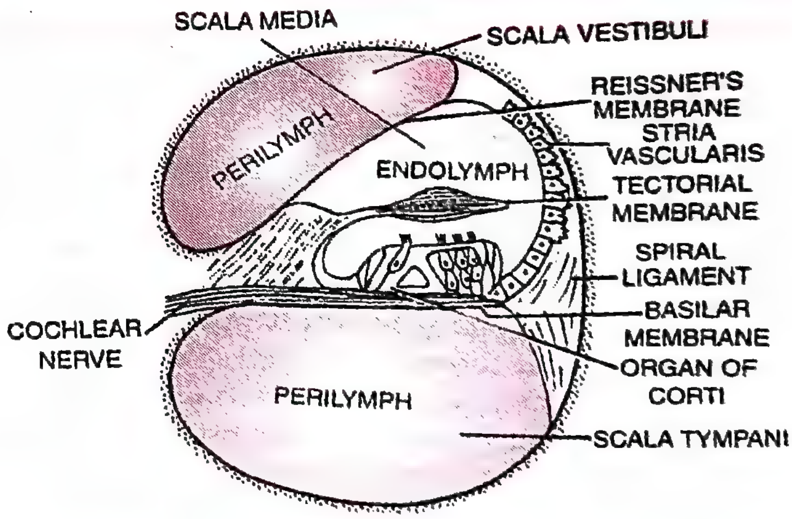


Fig. 21.36. T.S. Cochlea.

The scala media is the most important canal or channel of the cochlea. It bears an upper membrane, the **Reissner's membrane,** and lower membrane, **basilar membrane.** On the basilar membane a sensory ridge, the **organ of Corti** is present. The organ of Corti consists of **outer hair cells, inner hair cells, inner pillar cells, outer pillar cells, tunnel of Corti, phalangeal cells (cells of Deiters), cells of Hensen** and **cells of Claudius.** The sensory hairs project from the outer ends of the hair cells into the scala media, while from the inner end of the cells nerve fibres arise, which unite to form the **cochlear nerve.** The **tectorial membrane** overhangs the sensory hair in the scala media. Its properties are to determine the patterns of vibration of sound waves.

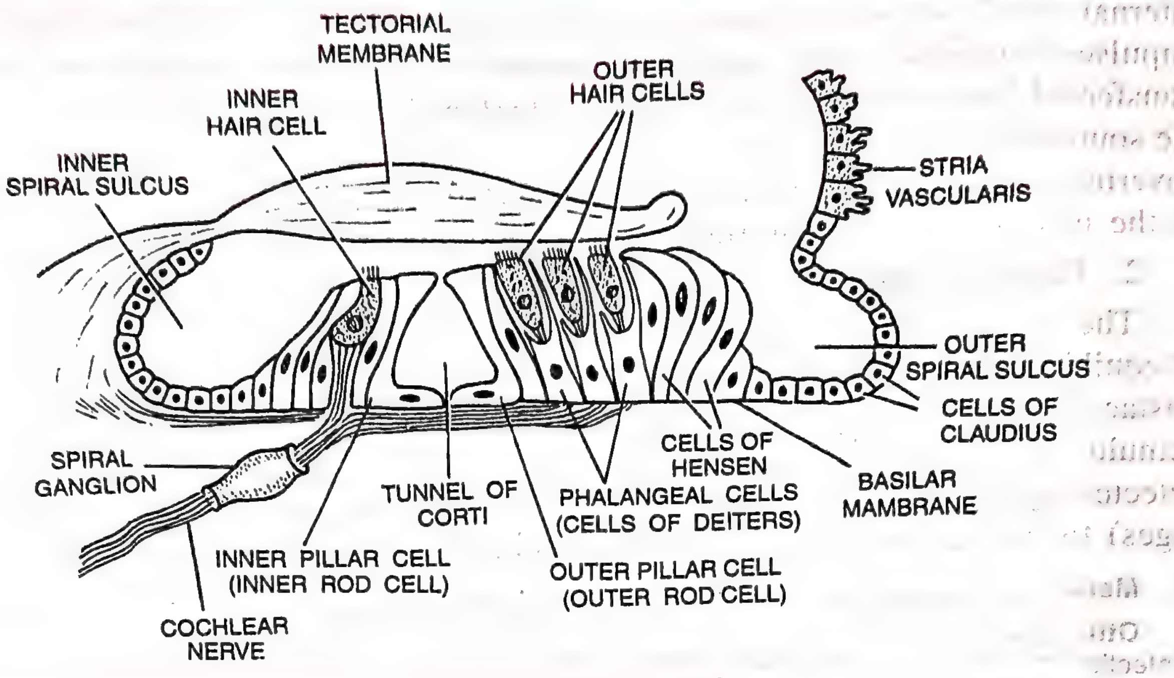


Fig. 21.37. Organ of Corti.

Functions of Ear

The ear performs two important functions : hearing and balancing (equilibrium).

1. Mechanism of Hearing

The external ear receives sound waves and directs them to the tympanic membrane. The tympanic membrane vibrates in response to the sound waves and these vibrations are transmitted through the ear ossicles (malleus, incus and stapes) to the fenestra ovales. The vibrations are passed through the fenestra ovalis on to the cochlea where they generate waves in the lymphs. The waves in the lymphs induce a small movement in the basilar membrane. These movements of the basilar membrane bend the hair cells of the organ of corti, pressing them against the tectorial membrane. As a result nerve impulses are generated in the afferent neurons. These impulses are transmitted by the afferent fibres via auditory nerve to the auditory cortex of the brain (**temporal lobe** of each cerebral hemisphere) where the impulses are analysed and the sound is recognised.

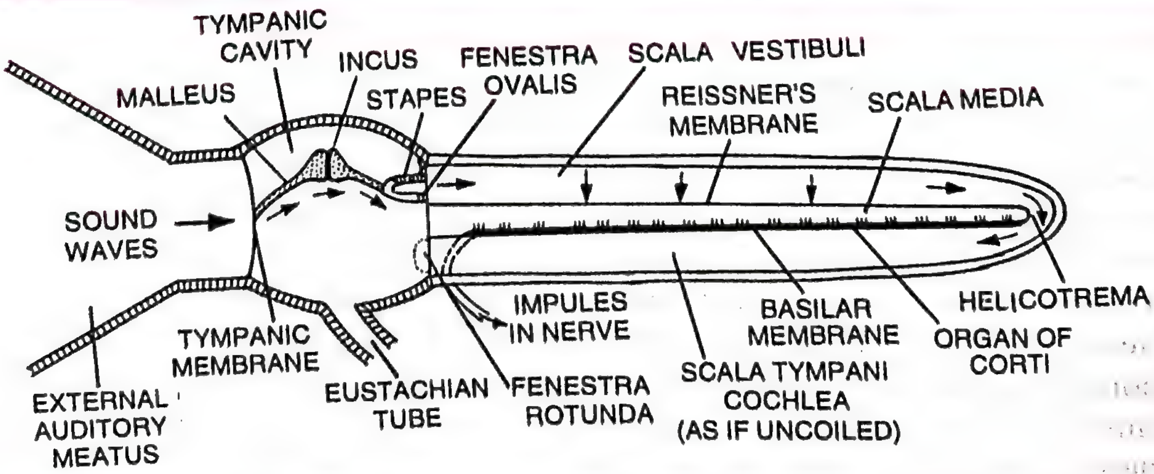


Fig. 21.38. Schematic representation of the conduction of sound vibrations in the ear.

It is evident that the external and middle ears serve to transmit sound waves to the internal ear. It is in the internal ear that the transformation of the vibrations into nerve impulses for relay to the brain takes place. During loud sound, some sound waves are transferred from scala vestibuli to scala tympani through helicotrema. From scala tympani the sound waves are transmitted to the tympanic or middle ear cavity through the membrane covering the fenestra rotunda. From the tympanic cavity the sound waves are transferred to the pharynx through the Eustachian tube.

2. **Equilibrium.**

The semicircular canals, utricle and saccule of membranous labyrinth are the structures of equilibrium (balancing). Whenever the animal gets tilted or displaced the hair cells of the cristae and maculae are stimulated by the movement of the endolymph and otolith. The stimulus is carried to the brain through the auditory nerve and the change of the position is detected by the medulla oblongata of the brain. After that, the brain sends impulses (messages) to the muscles to regain the normal conditions.

- **Meniere's Disease.** Spinning or whirling vertigo (dizziness) is characteristic of meniere's disease.
- **Otitis Media.** This is an acute infection of the middle ear caused mainly by bacteria and associated with infection of the nose and throat.

Sense of Touch (Skin Receptors)

Some skin receptors are only free nerve endings and may penetrate the epidermis. Other skin receptors possess connective tissue sheaths and mostly occur in the dermis and are often called **corpuscles** or **bulbs**. The skin has the following receptors :

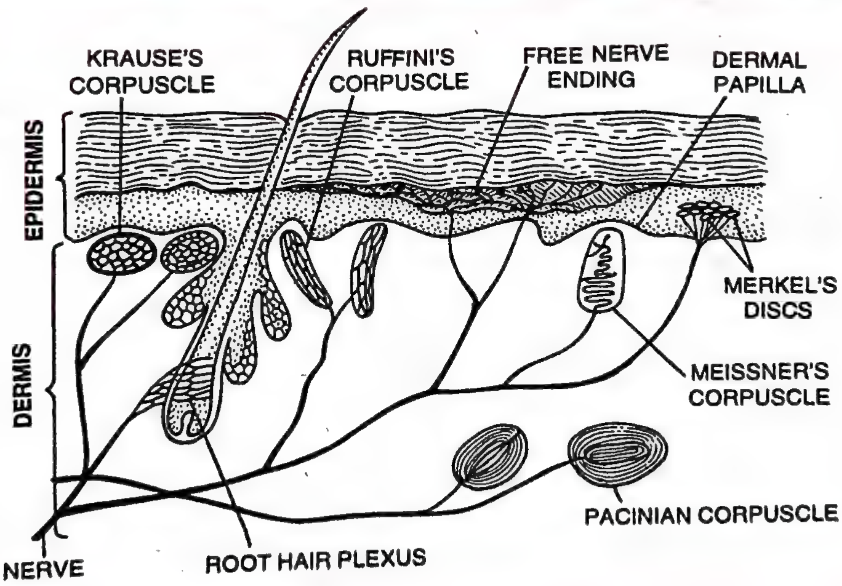


Fig. 21.39. Various skin receptors.

(i) **Free nerve endings** are distributed between cells of the epidermis. Most of these nerve endings are sensitive to pain. (ii) **Root hair plexus** is associated with the hair and responds to touch. (iii) **Meissner's corpuscles** are located in the papillary layer of the dermis just below the epidermis which respond to touch. (iv) **Merkel's discs** occur in the epidermis and are responsible for touch. (v) **Pacinian corpuscles** are in the dermis and respond to strong pressure. These receptors are located deep in the dermis. Pacinian corpuscles are also sensitive to vibrations. (vi) **Ruffini's corpuscles** respond to heat

(vii) **Krause's corpuscles** are excited by cold. The Krause corpuscles are far more numerous than the Ruffini's corpuscles. A large number of these receptors are found in the face and hands.

The Chemical Senses — The Taste and Smell

The receptors for taste and smell are classified as chemoreceptors as these respond to special chemicals in aqueous solution. In each case, the chemicals must go into solution in the film of liquid coating the membranes of the receptor cells before these can be detected. The taste receptors are specialized cells that detect chemicals present in quantity in the mouth itself, while smell receptors are modified sensory neurons in the nasal passage which detect the volatile chemicals that get wafted up the nostrils from distant sources. These two types of receptors complement each other and often respond to the same stimulus. We can now guess why a very strong perfume leaves a peculiar taste in your mouth. The smell receptors can be as much as 3,400 times more sensitive than the taste receptors.

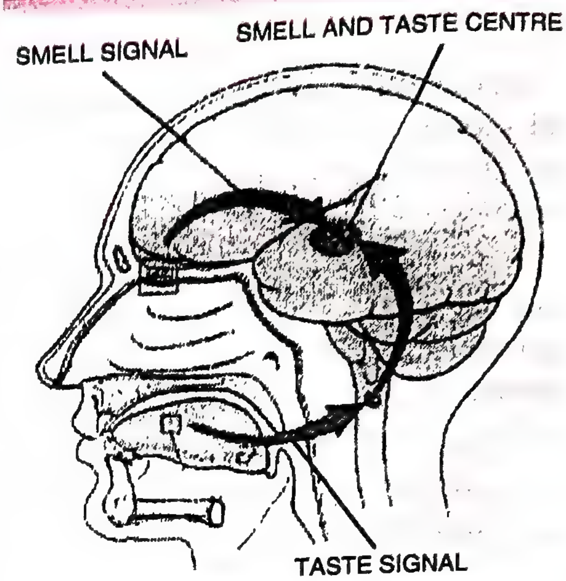


Fig. 21.40. Diagram showing smell signal, taste signal and smell and taste centre.

Sense of Smell (Olfaction)/Smell Receptors

Location. The receptors of smell occur in a small patch of **olfactory epithelium (pseudostratified epithelium)** located in the roof of the nasal cavity.

Structure. The olfactory epithelium is yellowish in colour and consists of three types of cells.

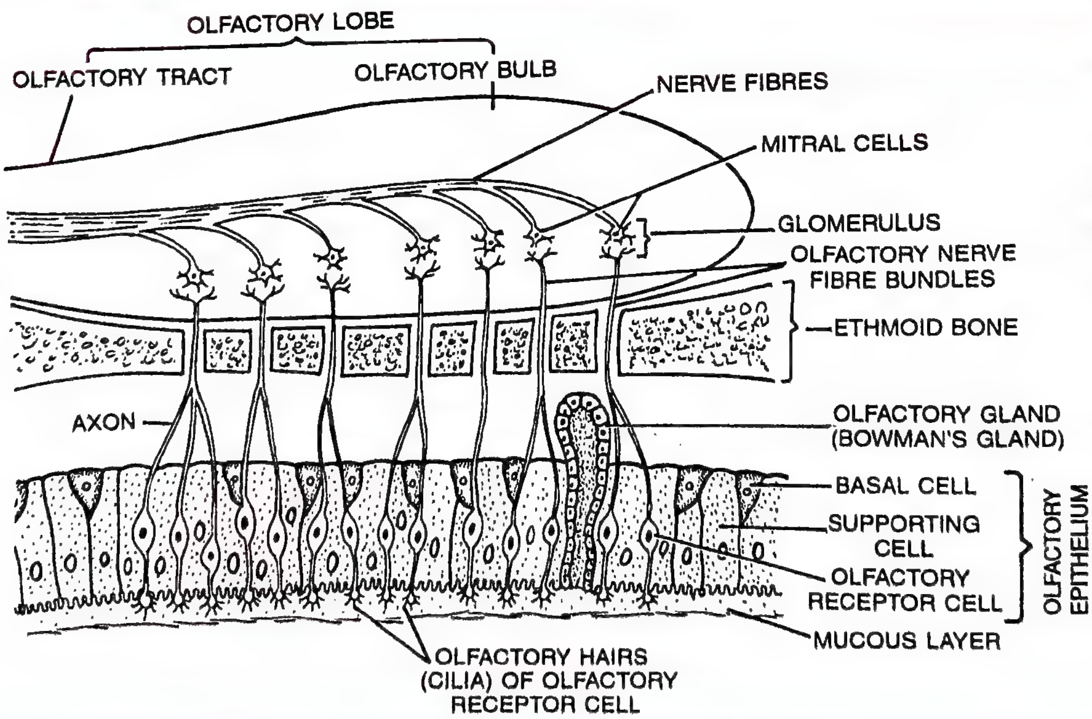


Fig. 21.41. Olfactory epithelium, ethmoid bone and olfactory lobe.

(i) **Olfactory Receptor Cells.** They act as sensory receptors as well as conducting neurons. The olfactory receptor cells are "unusual" bipolar neurons. Each cell is spindle shaped and has a thin apical dendrite that terminates in a knob which bears non motile cilia called **olfactory hairs**. Olfactory receptor cells are unique in that they are the only neurons that undergo turnover throughout adult life.

(ii) **Supporting Cells.** These are columnar cells which lie between the olfactory receptor cells to support them. They have brownish yellow pigment (similar to lipofuscin) which gives the olfactory epithelium its yellowish colour. Anatomical cells that support other cells are called **sustentacular cells.**

(iii) **Basal Cells.** These are short cells that do not reach the surface. They give rise to new olfactory receptor cells to replace the worn out ones. This is an exception to the fact that neurons are not formed in the postnatal (after birth) life. The olfactory receptor cells survive only for about two months.

Olfactory glands (Bowman's glands). Many olfactory glands occur below the olfactory epithelium that secrete mucus to spread over the epithelium to keep it moist. The mucus also protects the cells from dust and bacteria.

Working. The dissolved chemicals stimulate the olfactory receptors by binding to protein receptors in the olfactory hairs (cilia) membranes and opening specific Na^+ and K^+ channels. This leads ultimately to an action potential that is conducted to the first relay station in the **olfactory bulb**. The fibres of the olfactory nerves synapse with **mitral cells** (second-order neurons) in complex structures called **glomeruli** (balls of yarn). When the mitral cells are activated, impulses from the olfactory bulbs via **olfactory tracts** to main destinations (*e.g.*, temporal lobe of the cerebrum).

Women often have a keener sense of smell than men, especially at the time of ovulation. Smoking damages the olfactory receptors. With ageing the sense of smell deteriorates. **Hyposmia** (*hypo*– less, *osmi*– smell) is a reduced ability to smell.

Sense of Taste (Gustation) / Taste Receptors

Location. The receptors for taste are found in the **taste buds**, mostly located on the tongue but also found on the palate, pharynx and epiglottis and even in the proximal part of oesophagus. The number of taste buds declines with age.

Structure. Each taste bud is an oval body consisting of three kinds of cells.

(i) **Gustatory Receptor Cells.** They bear at the free end microvilli projecting into the **taste pore**. The microvilli have special protein receptor sites for taste-producing molecules and come in contact with the food being eaten. Nerve fibres of the cranial nerves VII (facial), IX (glossopharyngeal) or X (Vagus) end around the gustatory receptor cells, forming synapses with them. The gustatory receptor cells (taste cells) survive only about 10 days and are then replaced by new cells.

(ii) **Supporting Cells.** These cells lie between the gustatory receptor cells in the taste bud. They bear microvilli but lack nerve endings.

(iii) **Basal Cells.** These cells are found at the periphery of the taste bud. They produce supporting cells, which then develop into gustatory receptor cells.

Working. Specific chemicals in solution pass into the taste bud through the taste pore to come in contact with the protein receptor sites on the microvilli of the gustatory receptor cells. The latter set up nerve impulses in the sensory nerve fibres. The nerve fibres transmit the impulses to the taste centre in the brain (*e.g.*, parietal lobe of the cerebrum) where the sensation of taste arises.

The facial nerve (VII) serves the anterior two-thirds of the tongue, the glossopharyngeal nerve (IX) serves the posterior one-third of the tongue and the vagus nerve (X) serves the pharynx and epiglottis.

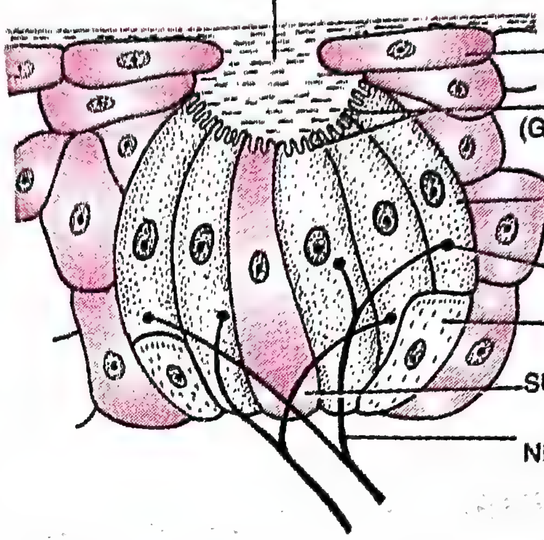


Fig. 21.42. Vertical section through a teste bud.

Basic Taste Areas. Human tongue has four basic taste areas : sweet, salty, sour and bitter as shown in the figure 21.43.

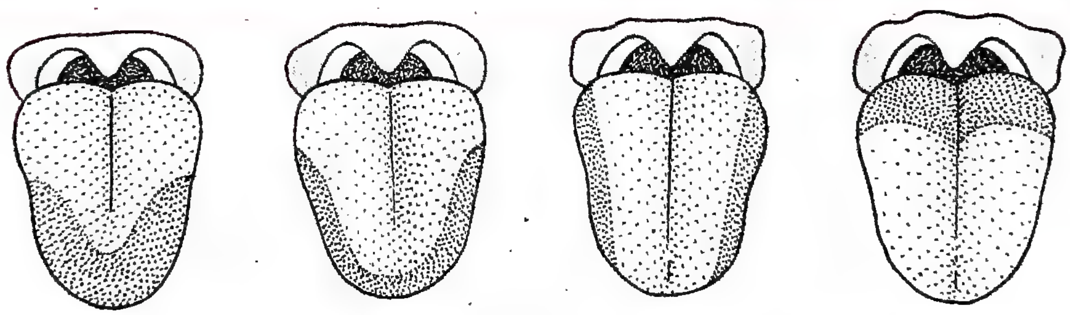


Fig. 21.43. Localization of different tastes on human tongue.

Differences between Taste Cells and Olfactory Cells

Taste Cells (Gustatoreceptors)	*Olfactory Cells (Olfactoreceptors)*
1. They occur in taste buds on tongue, palate, epiglottis and pharyngeal wall.	1. They occur in olfactory epithelium lining the roof of nasal cavity.
2. They are specialized epithelial cells.	2. They are bipolar neurons.
3. They function only as sensory receptors.	3. They function as sensory receptors as well as conducting neurons.
4. They are stimulated by chemicals that come in their contact in relatively high concentrations.	4. They are stimulated by chemicals from a distance and in much lower concentrations.
5. They only taste the food.	5. They smell as well as taste the food.

ADDITIONAL INFORMATION

- **Agnosia**— The term agnosia means a failure to recognize. It includes three types: tactile agnosia, visual agnosia, and auditory agnosia.
- **Alexia**— inability to read because of a lesion in the brain.
- **Agraphia**— inability to write because of a lesion in the brain.
- **Apraxia** – inability to carry out purposeful movements in the absence of paralysis.
- **Aphasia**— inability to speak or write because of a lesion in the brain.
- **Amnesia**— loss or lack of memory.
- **Analgesia**— insensibility to pain.
- **Anaesthesia**— loss of feeling.
- **Insomnia**— chronic inability to sleep.
- **Tropism**— is a response of a part of a sessile organism to the stimulus.
- **Taxis**— is a bodily movement of a motile organism by the direction of the stimulus.
- **EEG** (Electroencephalography) is for diagnosis of the diseases of the brain exactly in the same manner as ECG helps in diagnosing the disease affecting the heart.
- **Cranial Nerves**— The anamniotes (fishes and amphibians) have 10 pairs and amniotes (reptiles, birds and mammals) have 12 pairs of cranial nerves.
- Diagnosis of disorders of the brain can be made by examining cerebrospinal cord.
- Brain is the busiest organ of the body.
- The sluggish vertebrates have poorly developed cerebellum.
- Trigeminal nerve is often called "The dentist's nerve" because the dentist desensitizes this nerve with some anaesthetic before pulling out the troubling tooth.
- A 2-month old human baby crying for milk is an example of inborn reflex.
- It is said that injury to brain is permanent and nerve cells cannot regenerate or multiply because cells are very long.
- **Musician's Nerve**– ulnal nerve.
- Oculomotor, Pathetic (Trochlear) Abducens, Spinal accessory and Hypoglossal cranial nerves are motor.
- Olfactory, Optic and Auditory cranial nerves are sensory.
- Trigeminal, Facial, Glossopharyngeal and Vagus cranial nerves are mixed.
- **Labourer's Nerve**—Median nerve.
- **Sciatic nerve** is the largest nerve in the body.
- **Mydriasis**— abnormal enlargement of pupil.
- Autonomic nervous system was explained and coined by Langley (1921).
- **Ptosis**— falling or dropping of the eye lid.
- **Otalgia**— ear pain.
- **Eustachis**— infection or inflammation of eustachian tube.
- **Langerhans cells**—found in the epidermis, are modified macrophages circulating between the epidermis and the local lymph nodes whose prime function is presentation of antigen to T-lymphocytes.
- **Melanocytes**— are found mainly in the basal layer of the epidermis; they are the only epidermal cells capable of synthesising melanin which they transfer to surrounding keratinocytes.
- Fishes and snakes lack eyelids.
- Frog is short sighted in air and long sighted in water.
- Most domestic mammals and sharks lack colour vision.
- Most birds have only day vision as their retina has mainly cones.
- Owls have much better night vision as they contain a large number of rods and few cones in their retina.
- Birds generally have monocular vision. Owls have binocular vision.
- In cyclostomes and fish ear consists of membranous labyrinth only. Amphibians have middle ear and internal ear. Reptiles, birds and mammals have external ear, middle ear and internal ear.
- Aquatic mammals such as whales, sirenians and seals lack pinna. Platypus also does not have pinna.
- Snakes have no ear.
- **Hordeolum.** A localized circumscribed inflammatory swelling of one of several sebaceous glands of the eye lid. It is caused by a bacterial infection. External styes are superficial and affect the glands of Zeis or glands of Moll at the edge of the lid. Internal styles concern the meibomian or tarsal glands under the eyelid and are more severe.
- **Phaco-emulsification technique** in cataract surgery– "stitchless" technique. Foldable IOL (intraocular lens) is used.

- **Hartline, Wald** and **Granit** got Nobel Prize in 1967 for physiology or medicine for their discoveries concerning the chemical and physiological visual processes in eye.
- In proportion to body size, deer presumbly possesses largest eyes among vertebrates.
- Suspensory ligament is also called **Zonula of Zinn.**
- **Otoliths** are also called **otoconia** or **"ear dust"**. These are numerous white crystals of calcium carbonate.
- **Owls & cats** see only with the help of available light from the stars or moon at night.
- **Glands of Bowman** (Olfactory glands). They occur below the olfactory epithelia. Their ducts open on the olfactory epithelial surface. These glands secrete watery mucus to protect and keep the epithelium moist.
- Olfactory epithelium is also called **Schneiderian membrane.**
- **Harder's** or **Harderian gland.** It is a modified sebaceous gland found in many amphibians (*e.g.*, frog), reptiles (*e.g.*, *Uromastix*), birds (*e.g.*, pigeon) and some mammals (*e.g.*, whales, mice, shrews) but not rabbit and man. It secretes a lubricant for nictitating membrane.
- **Pecten.** It is a remarkable, highly vascular and pigmented structure projecting into the vitreous chamber from the blind spot normally. The pecten occurs in all birds except Kiwi (*Apteryx*). It is also found in some reptiles (*e.g.*, *Uromastix*) but is absent in mammals. In *Uromastix* it is like cushion however, in pigeon it is comb-like and folded like a fan. The actual function of pecten is unknown but possibly it aids in the nutrition of the eye ball. In birds, it also helps in accommodation which is remarkably well developed in birds, by pressing the lens forward.
- **Jacobson's organs (Vomero-nasal organs).** These are additional olfactory organs that are found in amphibians and reptiles. They are absent in rabbit but occur in certain lower mammals. In man these are vestigial. They are best developed in snakes.
- **Otology.** It deals with the study, diagnosis and treatment of the diseases of the ear and related structures.
- It is normal for a preschool child to be slightly far sighted (that is, they see distant objects more clearly).
- Aqueous and vitreous humours are rich in vitamin C.
- Cornea derives its nutrients from aqueous humour and lymph.
- Flat fishes have both eyes on the same side of the head.
- The "otolith organs" refer to the utriculus (utricle) and sacculus (saccule).
- Nerves and blood capillaries are transparent in the conjunctiva.
- Lens, retina and conjunctiva of vertebrate eye are derived from ectoderm.
- **Tapetum lucidum.** It is a part of choroid adjacent to the retina in the eyes of large number of **elasmobranchs** (cartilaginous fish). It possesses cells containing light-reflecting *guanine crystals.* It reflects light and causes the eyes to shine in dark. It also reflects additional light on the retinal cells to enable the fish to see in water where light is poor.
- Sclera and Choroid of the eye are derived from mesoderm.
- Crocodiles do not have tear glands.
- **Common Eye Defects. 1. Myopia** (short sightedness). In this eye defect, person has difficulty in seeing distant objects clearly.

  2. **Hypermetropia** (Farsightedness). In this eye defect the person has difficulty in seeing near objects.
  3. **Astigmatism**. It is due to irregular cornea or lens, causing the image to be out of focus, producing faulty vision. It is corrected by cylindrical lens.
  4. **Presbyopia** (Old sightedness). It is a defect in accommodation occurring in advancing age. Lens looses its elasticity and is not able to focus the image of near object while the distant vision is not impaired. This defect is corrected by using convex lens.
  5. **Strabismus**. It is commonly known as **squint**. In this defect, the eye ball is somewhat bent on to a side in its orbit so that the optic axes can not be directed to same object. Some extra-ocular muscles become longer or shorter than normal.
  6. **Cataract** (SAFAID MOTIA). In cataract, the lens loses its transparency and becomes opaque to light and hence vision is impaired. It is corrected by surgical removal of opaque lens and using biconvex glasses. Intraocular lens implantation is also done. Cataract is more common in older people but it can occur at any age.
  7. **Glaucoma** (KALA MOTIA). In glaucoma optic nerve may be damaged due to increase in intraocular pressure.

- **Golgitendon** is sensory nerve ending embedded among the fibres of a tendon
- Human eye is most sensitive to wave length of 500 nm.
- **Compound Eyes.** Compound eyes are present in many arthropods, (*e.g.*, Prawn, Crabs, Insects, King Crabs, etc.).
- **Blood-brain barrier.** It prevents passage of certain substances from blood to the nervous tissue. It is due to the reduced permeability of the blood capillaries in the nervous tissue.
- **Encephalogy** (Gr. *enkephalon*–brain, *logos*–discourse) is the study of all aspects of brain.
- **Reticular Activating System** (RAS). It is the diffuse network of nerve cell bodies and nerve tracts extends through the brain stem. It screens sensory information so that only certain impulses reach the cerebrum. This system is also important in activation and arousal. When certain neurons in RAS are active, a person is awake, when they are inhibited by other neurons, the person sleeps. The pons varolii and medulla oblongata have **sleep** centres that cause sleep when stimulated. Midbrain has an **arousal centre** which causes arousal.
- Taking milk before bedtime may induce sleep as milk has a lot of amino acid tryptophan, from which serotonin is synthesized. Serotonin may be the neurotransmitter of the sleep-causing centres in the pons varolii and medulla oblongata.
- Insects have taste receptors on the feet.
- Chillies and peppers stimulate the pain receptors in the mouth.
- Albinos lack pigment in the skin, hair and iris. Pink colour of their iris is due to reflection of light from the blood vessels of iris.
- **Anosmia.** Loss of sensation of smell.
- **Hyposmia.** Reduction in olfactory sensation due to constant exposure to a particular odour (like excessive perfume).
- **Hyperosmia.** Increased olfactory sensation.
- **Ageusia.** Loss of taste sensation.
- **Hypogeusia.** Decrease in the taste sensation.
- **Dysgeusia.** Disturbance in the taste sensation.
- **Diplopia** means double vision.
- **Dementia.** Progressive loss of memory.
- **Dyslexia.** Difficulty in learning to read.
- **Apnea.** A sleep disorder in which sleepers stop breathing and thus wake up many times each time.
- **Neopallium.** It is that part of cerebral cortex of vertebrates which is specially large in higher mammals. It forms a thickening in the dorsal region near the hippocampal lobes. Its chief function is general co-ordination and intelligence.
- **Golgi Mazzoni Corpuscle.** It is an encapsulated sensory nerve ending similar to a Pacinian corpuscle.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. 1. Compare the following : (a) Central neural system (CNS) and Peripheral neural system (PNS), (b) Restin potential and action potential. (c) Choroid and retina.

✓ (a)

Differences between Central Neural System (CNS) and Peripheral Neural System (PNS)

Central Neural System (CNS)	*Peripheral Neural System (PNS)*
1. It lies in the center of the body.	1. It lies in the periphery of the body.
2. In vertebrates it consists of brain and spinal cord.	2. In vertebrates it compries cranial nerves (connect the brain) and spinal nerves (connect the spinal cord).
3. The groups of neurons are called nuclei.	3. The groups of neurons are called ganglia.
4. Brain in vertebrates is protected by the cranium (brain box) which is present in the skull. Spinal cord is protected by vertebral column (back bone).	4. Such protective structures are not found.
5. Brain and spinal cord receive stimuli from the receptors (sense organs) and act through effectors.	5. Cranial and spinal nerves carry stimuli from receptors to the brain and spinal cord and from brain and spinal cord to the effectors.

(b)

Differences between Resting Potential and Action Potential

Resting Potential	*Action Potential*
1. It is potential difference across the membrane when neuron is resting.	1. It is a potential difference across the membrane when the neuron is stimulated.
2. At resting potential, a nerve fibre is not conducting an impulse. Although both the Na^+ and K^+ channels remained closed during resting potential, yet the membrane of the neuron is moderately permeable to Na^+ and quite (50 to 100 times more) permeable to K^+ and Cl^- ions.	2. During action potential, the neuron membrane is more permeable to sodium due to opening of Na^+ channels. The K^+ channels remain closed.
3. In resting potential the interior of neuron is electronegative and the exterior is electro positive.	3. In action potential the interior of neuron is electropositive and the exterior is electronegative polassium.
4. An active sodium potassium pump operates.	4. No sodium pump is operating.

(c)

Differences between Choroid and Retina

Choroid	*Retina*
1. It is middle layer of eye.	1. It is inner layer of eye.
2. It does not contain photosensitive cells.	2. It contains photo sensitive cells : rods and cones.
3. It is vascular layer.	3. It is nervous layer.
4. No image is formed on choroids.	4. Inverted image is formed on retina.

2. Write short notes on the following : (a) Neural coodination (b) Forebrain (c) Hindbrain (d) Midbrain (e) Retina (f) Ear ossicles (g) Cochlea (h) Organ of Corti (i) Synapse.

✓ (a) **Neural Coordination.** Co-ordination is a process through which two or more organs interact and complement the function of each other. When it is done through neural system it is called neural co-ordination. (b), (c) and (d); Refer to the text Human Brain. (e) Retina; Refer to the text Parts of Human Eye. (f) Ear ossicles; Refer to text Parts of Human Ear. (g) and (h) Refer to the text Internal Ear. (i) Refer to the text Synapse.

3. Answer briefly : (a) How do you perceive the colour of an object ? (b) Which part of our body helps us in maintaining the body balance ? (c) How does the eye regulate the amount of light that falls of on the retina.

✓ (a) There are three types of cone cells corresponding to three primary colours of red, green and blue. Cones contain iodopsin. Light induces dissociation of iodopsin into opsin and retenene. Specific changes in opsin set in a reaction involving transducin, cGMP and Na^+ channels. This produces a signal that generates action potential in the ganglion cells through bipolar cells. The action potential is conducted by the optic nerve fibres to the visual area of occipital lobe of the cerebral hemisphere where erect image formed is recognised.

(b) Cristae and maculae present in internal ears.

(c) The iris contains two sets of smooth muscles : circular (sphincter) and radial (dilator). In bright light, the circular or sphincter muscles contract. The pupil (aperture of iris) becomes narrow so that less light enters the eye. In dim light the radial or dilator muscles contract. Pupil becomes wide so that more light enters the eye.

4. Explain the following (a) Role of Na^+ in the generation of action potential (b) Mechanism of generation of light-induced impulse in the retina (c) Mechanism through which a sound produces a nerve impulse in the inner ear.

✓ (a) When the nerve fibre is stimulated with thereshold stimulus, the sodium ions move into the nerve fibres and simultaneously the potassium ions move out. So, the membrane becomes negatively

charged from outside and positively charged from inside. The membrane is now said to be **depolarised** and the sudden change in the membrane potential is called the **action potential.** It results in forming wave of excitation along the nerve fibre which is called **nerve impulse.**
(b) Light induces the dissociation of retinene and opsin, this results in change in the structure of opsin. It generates action potential in the bipolar neurons. These impulses/action potential are transmitted by the optic nerve to the visual cortex of the brain where the neural impulses are analysed and image formed is recognised.
(c) Refer to the text Function of Ear (Mechanism of Hearing).

5. Differentiate between : (a) Myelinated and non-myelinated axons. (b) Dendrites and axons. (c) Rods and cones. (d) Thalamus and Hypothalamus. (e) Cerebrum and Cerebellum
✓ (a)

Differences between Myelinated Axons and Non-myelinated Axons

Myelinated Axons	*Non-myelinated Axons*
1. Medullary sheath is present.	1. Medullary sheath is absent.
2. Nodes of Ranvier are present.	2. Nodes of Ranvier are absent.
3. Collateral nerve fibres are present.	3. Collateral nerve fibres are absent.
4. They carry impulses faster than non-medullated nerve fibres.	4. They carry impulses slower than medullated nerve fibres.

(b)

Differences between Dendrites and Axons

Dendrites	*Axons*
1. They conduct the impulses towards the cell body.	1. They conduct the impulses away from the cell body.
2. The terminals of dendrites become as receptors.	2. Axon ends in a group of branches called terminal arborizations (axon endings or presynaptic knobs).

(c) Refer to the text Differences between Rods and Cones.
(d)

Differences between Thalamus and Hypothalamus

Thalamus	*Hypothalamus*
1. It is present below the cerebrum.	1. It represents the lower part of the diencephalon.
2. It is the major co-ordinating center for sensory and motor signaling.	2. It is major center for regulation of body temperature, thirst, hunger, etc.
3. It does not secrete any hormone.	3. It secretes several hormones.

(e) Refer to the text Differences between cerebrum and cerebellum.

6. Answer the following : (a) Which part of the ear determines the pitch of a sound ? (b) Which part of the human brain is the most developed ? (c) Which part of our central neural systems acts as a master clock ?
✓ (a) Middle ear (b) Cerebrum (c) Pineal Body

7. The region of the vertebrate eye, where the optic nerve passes out of the retina, is called the (a) fovea (b) iris (c) blind spot (d) optic chiasma.
✓ (c)

8. Distinguish between:
(a) afferent neurons and efferent neurons
(b) impulse conduction in a myelinated nerve fibre and unmyelinated nerve fibre
(c) aqeous humor and vitreous humor

(d) blind spot and yellow spot
(e) cranial nerves and spinal nerves.
✓ (a)

Differences between Afferent Neurons and Efferent Neurons	
Afferent Neurons	*Efferent Neurons*
1. They conduct impulses towards the central neural system.	1. They conduct impulses away from central neural system.
2. They pick up information from the receptors.	2. They take information to effectors.
3. They are sensory in nature.	3. They are motor in nature.
4. Information is picked up by dendrite terminals.	4. Impulse is passed on to effector by axon terminal.

(b)

Differences between Impulse Conduction in Myelinated Nerve Fibre and Impulse Conduction in Unmyelinated Nerve Fibre	
Impulse Conduction in Myelinated Nerve Fibre	*Impulse Conduction in Unmyelinated Nerve Fibre*
1. The depolarisation occurs only in the nodes of Ranvier where myelin sheath is absent.	1. Depolarisation occurs all along the length of the nerve fibre.
2. Action potential jumps from one node of Ranvier to another.	2. Action potential travels along the entire length of the fibre.
3. Conduction is much faster and is called saltatory conduction.	3. Conduction is slower.
4. Energy expenditure is less.	4. More energy is spent on depolarization.

(c) Refer to the text Differences between Aqueous Humour and Vitreous Humour.
(d) Refer to the text Differences between Blind Spot and Yellow Spot.
(e)

Differences between Cranial Nerves and Spinal Nerves	
Cranial Nerves	*Spinal Nerves*
1. They come out of the brain.	1. They come out of the spinal cord.
2. In human being, cranial nerves are 12 pairs.	2. In human being spinal, nerves are 31 pairs.
3. Cranial nerves are sensory, motor or mixed in nature.	3. Spinal nerves are mixed in nature.
4. Preganglionic fibres of parasympathetic neural system which come from the brain run along III, VII, IX and X cranial nerves.	4. Preganglionic fibres of parasympathetic neural system which come from the spinal cord pass through 2, 3 and 4 sacral spinal nerves.

9. Briefly describe the structure of the following (a) Brain (b) Eye (c) Ear.
✓ Refer to the text Brain, Eye and Ear.
10. Explain the following processes : (a) Polarisation of the membrane of nerve fibre (b) Depolarisation of the membrane of a nerve fibre (c) Conduction of a nerve impulse along a nerve fibre (d) Transmisssion of a nerve impulse across a chemical synapse.
✓ (a) Refer to the text Polarisation Generation and Conduction of Nerve Impulse.
(b) Refer to the text Depolarisation Generation and Conduction of Nerve Impulse.

(c) Refer to the text Generation and Conduction of Nerve Impulse.
(d) Refer to the text Transmission of Impulses Between Neurons.

11. Draw labelled diagram of the following; (a) Neuron (b) Brain (c) Eye (d) Ear.
✓ Refer to the text under the heading (a) Neurons as structural and functional unit of Neural System; (b) Human Brain (c) Parts of Human Eye (d) Parts of Human Ear.

12. Give a brief account of : (a) Mehanism of synaptic transmission (b) Mechanism of vision (working of eye). (c) Mechanism of hearing.
✓ (a) Refer to the text Transmission of Nerve Impulse at the chemical synapse; (b) Refer to the text Working of Eye ; (c) Refer to the text Functions of Ear.

TEST QUESTIONS

One Mark Questions (With Answers)

1. What constitutes brain stem ?
✓ The medulla oblongata, pons varolii and mid brain are collectively called the brain stem.
2. How diameter of an axon affects the speed of an impulse ?
✓ The impulse travels slower in a thinner fibre than in a thicker one.
3. Why cornea can be easily transplanted ?
✓ It lacks blood vessels
4. Give the technical names of the auditory ossicles in their natural sequence.
✓ Malleus, Incus and Stapes.
5. How do you call the conduction of impulse along a myelinated nerve fibre ?
✓ Saltatory conduction
6. Which lobe of cerebrum has the somaesthetic area ?
✓ Frontal lobe
7. Name the band of nerve fibres that joins the cerebral hemispheres.
✓ Corpus callosum
8. Which part of the eye has the same name as the Greek goddess of the rainbow.
✓ Iris

Two Mark Questions (With Answers)

1. Why are dogs used in crime detection ?
✓ The receptors of smell occur in the form of olfactory epithelium, which is very extensive in dogs. They have an acute olfactory sense, so they are used in crime detection.
2. Why is the mode of conduction of electrical impulse along the myelinated neurons advantageous to a non-myelinated neuron ? What is this type of conduction called ?
✓ Conduction along the myelinated neurons is called saltatory conduction. This is energetically economical for the cell because there is far less membrane depolarisation for the ion pumps to deal with. Since the lipid-rich myelin acts as an insulator, the action potential jumps from one node of Ranvier to the other. So conduction is rapid and occurs at the rate of 120m/sec. in large diameter neurons.
3. Name the parasympathetic nerves that innervate the eye. Mention the function of each. Specify the neurotransmitter liberated by these nerves at the synapse.
✓ Occulomotor nerve and facial nerve. Oculomotor nerve controls the eye ball movement. Facial nerve stimulates the tear gland to secrete tear. Both the nerves release acetylcholine as neurotransmitter in the synapse.
4. Name the parasympathetic nerve from the brain that innervates most of the visual organs. List any four functions of this nerve.
✓ Vagus nerve (i) It slows down the heart beat.
(ii) It speeds peristalsis.
(iii) It constricts respiratory passage.
(iv) It promotes gastric and pancreatic secretions.

Three Mark Questions (Short Answer Type)

1. Draw a labelled diagram of a neuron with a myelin sheath.
2. Draw a line sketch to show the image formation on the retina of human eye.
3. How ear helps in maintaining equilibrium ?
4. What type of striated muscles constitute the muscles of the eyeball ? How is this specific type of muscles advantageous ?

Five Mark Questions (Long Answer Type)

1. Describe the structure of human brain.
2. Describe the major events occurring during the transmission of a nerve impulse.
3. Describe the structure of human eye.
4. Explain the mechanism of vision in human eye.
5. What is a synapse ? How does the nerve impulse cross the synapse ?

Multiple Choice Questions (With Answers)

(1) Which one of the following cranial nerves is carrying the nerve fibres originating from the Edinger Westphal nucleus ? (a) Oculomotor (b) Trochlear (c) Abducens (d) Vagus. *(WB JEE 2010)*

(2) In brain, lateral ventricle is connected to diocoel by (a) foramen of Magendie (b) foramen of Monro (c) foramen of Luschka (d) both (a) and (b). *(Orissa JEE 2010)*

(3) The brain stem is made up of (a) midbrain, pons, cerebellum (b) midbrain, pons, medulla oblongata (c) diencephalon, medulla oblongata, cerebellum (d) cerebellum, cerebrum, medulla oblongata. *(Karnataka CET 2011)*

(4) Which one of the following substances can cure Parkinson's disease ? (a) GABA (b) Acetylcholine (c) Dopamine (d) Glutamic acid. *(West Bengal JEE 2011)*

(5) Electric potential of the brain is recorded by (a) CT scan (b) sphygmomanometer (c) ECG (d) EEG. *(West Bengal JEE 2011)*

(6) The electrical potential difference between outside and inside of a nerve axon before excitation is known as (a) resting potential (b) action potential (c) spike potential (d) reaction potential (e) activation potential. *(Kerala PMT 2011)*

(7) Which part of the human ear plays no role in hearing as such but is otherwise very much required ? (a) Eustachian tube (b) Organ of Corti (c) Vestibular apparatus (d) Ear ossicles. *(CBSE PMT Prelims 2012)*

(8) A person entering an empty room suddenly finds a snake right in front on opening the door. Which one of the following is likely to happen in his neuro-hormonal control system ? (a) Sympathetic nervous system is activated releasing epinephrine and norepinephrine from adrenal medulla (b) Neurotransmitters diffuse rapidly across the cleft and transmit a nerve impulse (c) Hypothalamus activates the parasympathetic division of brain (d) Sympathetic nervous system is activated releasing epinephrine and norepinephrine from adrenal cortex. *(CBSE PMT Prelims 2012)*

(9) Dark adaptation in human eye involves (a) conversion of 11 *cis* retinene to *trans* retinene (b) conversion of *trans* retinene to *cis* retinene (c) decomposition of rhodopsin into retinene (d) decomposition of rhodopsin to scotopsin. *(AMU 2012)*

(10) The number of spinal nerves in human is (a) 10 pairs (b) 12 pairs (c) 43 pairs (d) 31 pairs. *(West Bengal JEE 2012)*

(11) During synaptic transmission of nerve impulse, neurotransmitter (P) is released from synaptic vesicles by the action of ions (Q). Choose the correct P and Q. (a) P = acetylcholine, Q = Ca^{++} (b) P = acetylcholine, Q = Na^{++} (c) P = GABA, Q = Na^{+} (d) P = Cholinesterase, Q = Ca^{++}. *(West Bengal JEE 2012)*

(12) Third and fourth ventricles of the brain are connected by (a) aqueduct of Sylvius (b) foramen of Monro (c) foramen of Magnum (d) corpus callosum. *(West Bengal JEE 2012)*

(13) Put the following parts of a reflex arc in the correct order beginning with the sensory receptor.

A. Motor neuron B. Interneuron C. Effector

D. Sensory neuron E. Sensory receptor

(a) E, D, B, A, C (b) E, D, A, B, C (c) A, B, C, D, E (d) A, E, D, B, C *(Karnataka CET 2013)*

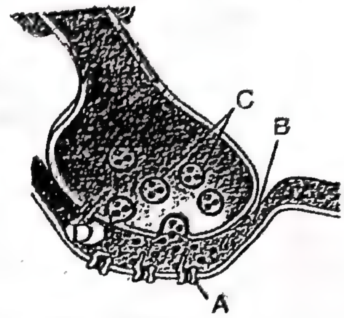
(14) Retina is composed of (a) rod only (b) cones only (c) rods and cones (d) rods, cones and neuroqanglion cells. *(J & K CET 2013)*

(15) Which is the largest bone in middle ear? (a) Incus (b) Malleus (c) Stapes (d) Cochlea. *(J & K CET 2013)*

(16) The following respond to pressure (a) Meissner's corpuscle (b) Pacinian corpuscle (d) Bulbs of Krause (d) Organ of Ruffini. *(AMU Med. 2013)*

(17) The organ of Corti is situated on the (a) basilar membrane in the tympanic canal (b) Reissner's membrane in the vestibular canal (c) basilar membrane in the median canal (d) Reissner's membrane in the tympanic canal. *(AMU Med. 2013)*

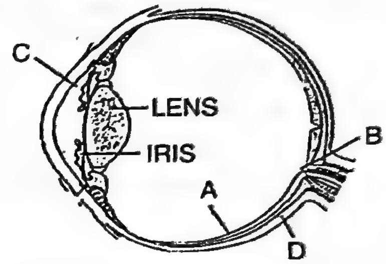
(18) A diagram showing axon terminal and synapse is given. Identify correctly at least two of A-D.



(a) A- Receptor
C - Synaptic vesicles
(b) B - Synaptic connection
D - K^+
(c) A - Neurotransmitter
B - Synaptic cleft
(d) C - Neurotransmitter
D - Ca^{++}

(NEET 2013)

(19) Parts A, B, C and D of the human eye are shown in the diagram. Select the option which gives correct identification along with its functions/characteristics.



(a) A - Retina - contains photo receptors - rods and cones
(b) B - Blind spot - has only a few rods and cones
(c) C - Aqueous chamber - reflects the light which does not pass through the lens
(d) D - Choroid - its anterior part forms ciliary body

(NEET 2013)

(20) Which area of cerebral cortex is responsible for the interpretation of speech? (a) Broca's area (b) Wernicke's area (c) Premotor area (d) Association area of sensory cortex. *(WB-JEE 2014)*

(21) The stato-acoustic receptor responds to changes in the .... (a) light and pressure (b) pressure and touch (c) pain and pressure (d) sound and equilibrium. *(Maharashtra CET 2014)*

(22) Which excrtatory neurotransmitter is involved in the transmission of impulse at the neuro-muscular junction? (a) Epinephrine (b) Serotonin (c) Acetylcholine (d) Glycine. *(WB-JEE 2014)*

(23) Select the correct statement regarding the Schwann cells. (a) surround axon of myelinated nerve fibre (b) support muscle fibres (c) found in Haversian system of bones (d) form basement membrane of epithelium. *(Maharashtra CET 2014)*

(24) The depolarization of nerve membrane takes place through influx of .... ions. (a) calcium (b) potassium (c) sodium (d) magnesium. *(Maharashtra CET 2014)*

(25) Which of the following statements is wrong regarding conduction of nerve impulse? (a) In a resting neuron, the axonal membrane is more permeable to K^+ ions and nearly impermeable to Na^+ ions (b) Fluid outside the axon has a high concentration of Na^+ and low concentration of K^+, in a resting neuron (c) Ionic gradients are maintained by Na–K pumps across the resting membrane, which transport 3 Na^+ ions outwards for $2K^+$ ions into the cell (d) Resting potential is the electrical potential difference across the resting membrane (e) A neuron is polarized only when the outer surface of the axonal membrane possess a negative charge and its inner surface is positively charged. *(Kerala PMT 2014)*

(26) In mammalian eye, the 'fovea' is the center of the visual field, where (a) high density of cones occur, but has no rods (b) the optic nerve leaves the eye (c) only rods are present (d) more rods than cones are found. *(CBSE 2015)*

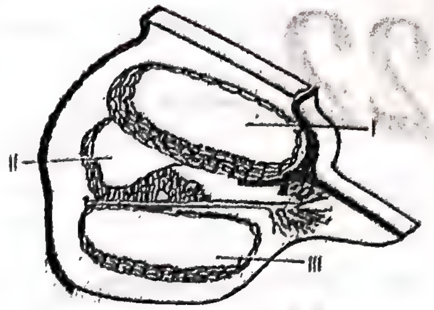
(27) Destruction of the anterior horn cells of the spinal cord would result in loss of (a) sensory impulses (b) voluntary motor impulses (c) commissural impulses (d) integrating impulses. *(CBSE 2015)*

(28) Which one of the following is the functional unit of hearing ?
(a) Utricle (b) Organ of Zuckerkand (c) Organ of Corti (d) Vestibular apparatus. *(WB JEE 2015)*

(29) Which one of the following is not a refractive medium of the eye ?
(a) Lens (b) Vitreous humour (c) aqueous humour (d) Pupil. *(WB JEE 2015)*

(30) Which one of the following acts solely as an inhibitory neurotransmitter ? (a) Norepinephrine (b) Gamma (γ) amino butyric acid (c) Acetylcholine (d) Dopamine. *(WB JEE 2015)*

(31) Select the correct identification group of labelled parts I, II, III.
(a) I - Scala vestibuli, II - Scala media, III - Scala tympani (b) I - Scala vestibuli, II - Scala tympani, III - Scala media, (c) I - Scala tympani, II - Scala media, III - Scala vestibuli (d) I - Scala media, II - Scala tympani, III - Scala media. *(MH CET 2015)*



(32) Which part is not included in Cochlear duct ? (a) Tectorial membrane (b) Macula of utricle (c) Scala media (d) Reissner's membrane. *(Gujarat CET 2015)*

(33) Photosensitive compound in human eye is made up of
(a) Opsin and Retinal (b) Opsin and Retinol (c) Transducin and Retinene (d) Guanosine and Retinol. *(NEET-I-2016)*

(34) Choose the correct statement. (a) Nociceptors respond to changes in pressure (b) Meissner's corpuscles are thermoreceptors (c) Photoreceptors in the human eye are depolarised during darkness and become hyperpolarised in response to the light stimulus (d) Receptors do not produce graded potentials. *(NEET-II-2016)*

(35) Receptor sites for neurotransmitters are present on
(a) pre-synaptic membrane (b) tips of axons (c) post-synaptic membrane (d) membranes of synaptic vesicles. *(NEET 2017)*

(36) Good vision depends on adequate intake of carotene rich food. Select the best option from the following statements.
(1) Vitamin A derivatives are formed from carotene
(2) The photopigments are embedded in the membrane discs of the inner segment
(3) Retinal is a derivative of vitamin A (4) Retinal is a light absorbing part of all the visual photopigments.
(a) (1), (3) and (4) (b) (1) and (3) (c) (2), (3) and (4) (d) (1) and (2). *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as–
*(a) If both **A** and **R** are true and **R** is the correct explanation of **A***
*(b) If both **A** and **R** are true and **R** is not the correct explanation of **A***
*(c) If **A** is true but **R** is false.*
*(d) If both **A** and **R** are false.*

1. **Assertion :** Rabies is an acute infectious disease of warm blooded mammals characterized by involvement of central nervous system resulting in paralysis and finally death.
Reason : This is caused due to neurotropic filterable bacteria in saliva of rabid animals.
(A) (B) (C) (D) *(AIIMS 2000)*
2. **Assertion:** Hearing aids help the hearing impaired to hear.
Reason: They make sound travel through skull bones.
(A) (B) (C) (D) *(AIIMS 2000)*
3. **Assertion:** Imbalance in Na^+, K^+ and proteins generates the resting potential.
Reason: To maintain inequal distribution of Na^+ and K^+, neurons use electrical energy.
(A) (B) (C) (D) *(AIIMS 2002)*
4. **Assertion:** Owls move freely during night.
Reason: They have large number of rods on their retina.
(A) (B) (C) (D) *(AIIMS 2003)*

ANSWERS

Multiple Choice Questions

(1) —a (2) —b (3) —b (4) —c (5) —d (6) —b (7) —c (8) —a (9) —b (10) —d
(11) —a (12) —a (13) —a (14) —d (15) —b (16) —b (17) —c (18) —a (19) —d (20) —d
(21) —c (22) —b (23) —d (24) —b) (25) —e (26) —a (27) —b (28) —c (29) —d (30) —b
(31) —a (32) —b (33) —a (34) —c (35) —c (36) —b

Assertion and Reason Type Questions

(1) —C (2) —D (3) —D (4) —B

22 CHEMICAL COORDINATION AND INTEGRATION

Types of Glands

In the vertebrate body glands may be classified on the basis of presence or absence of ducts. These are exocrine glands and endocrine glands.

1. **Exocrine glands** (glands with ducts). The secretions of these glands are carried by ducts to a particular organ for some metabolic activity, *e.g.*, salivary glands, liver, etc.

2. **Endocrine glands** (ductless glands) or **glands of internal secretions.** These glands have no ducts and their secretions get absorbed into the immediate surrounding blood circulation to reach the specific organs to initiate a particular metabolic change. The endocrine (Gr. *endo–* within, *krinien–* to secrete) glands secrete chemicals called **hormones** or internal secretions. Infact, *Hormones are non-nutrient chemicals which act as intercellular messengers and are produced in trace amounts.*

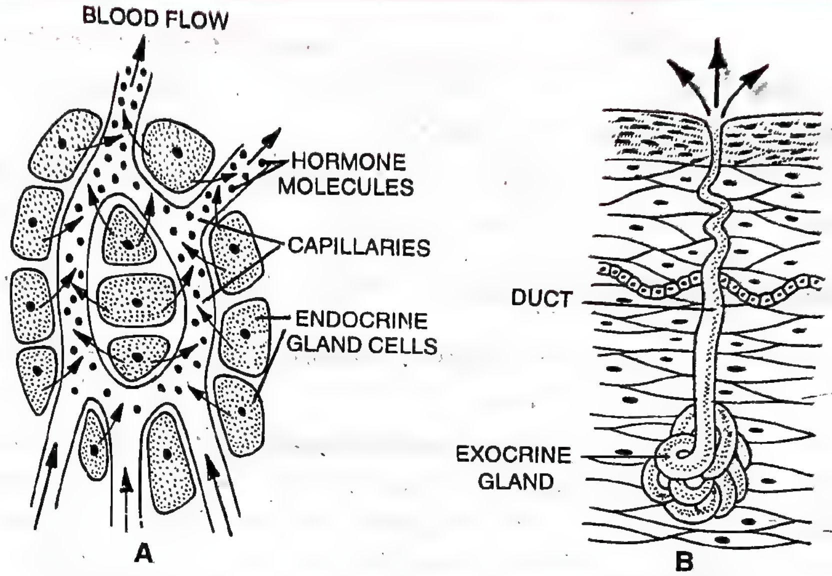


Fig. 22.1. A, An endocrine gland releasing hormone; B, An exocrine gland releasing secretion through a duct.

The endocrine glands which secrete only hormones are called the **holocrine glands** (*e.g.*, thyroid, parathyroids, adrenals, pituitary gland). The glands which have dual functions (secretion of hormones and some other functions) are termed the **heterocrine glands** (*e.g.*, pancreas, testes, ovaries, etc).

The study of endocrine glands and hormones secreted by them is called **endocrinology.**

Discovery of Hormones

The first hormone was discovered by the English physiologist **William M. Bayliss** and **Ernest H. Starling** in 1903. The term hormone was introduced by Starling in 1905.

Properties of Hormones (General Characteristic Features of Hormones)

(1) They are synthesized and secreted by living endocrine glandular cells within the body or in cultures of endocrine cells *in vitro* (artificial medium). *Hormones are non-nutrient chemicals which act as intercellular messengers and are produced in trace amount.* (2) Hormones are transported by the blood stream from the endocrine cells to serve as

'**chemical messenger**' which act on **target cells** or **organs**. (3) Hormones do not provide energy or building materials but they do have effects on growth differentiation and metabolic activities of their target cells. (4) They have low molecular weight. (5) Hormones belong to different types of chemical structure. They may be amino acid derivatives, peptides, polypeptides (proteins) or steroids. (6) Hormones are effective in low concentration. (7) Excess or deficiency leads to disorders. (8) They may accelerate or inhibit specific physiological process. (9) Many hormones are produced in inactive form called **prohormones**. For example, insulin is secreted as proinsulin. (10) Hormones are often used up in their regulatory action.

Hypo-and Hyperactivity of Hormones

When hormones are secreted in deficiency, the role of the hormones decreases which leads to hypoactivity of the hormones. Excess secretion of the hormones increases hormone action which is called hyperactivity of the hormones.

Hypoactivity or hyperactivity of the hormones can cause disorders. For example, defeciency of insulin causes diabetes mellitus. Excess of growth hormone from early age causes gigantism.

Types of Hormones Based on their Chemical Nature

1. **Amino Acid Derivative Hormones.** Epinephrine and norepinephrine are derived from the amino acid tyrosine. Melatonin and serotonin are derived from tryptophan.

2. **Peptide Hormones and Protein Hormones.** Examples of peptide hormones are hypothalamic hormones (*e.g.*, antidiuretic hormone (ADH), Oxytocin). Protein hormones include insulin, glucagon, pituitary hormones (*e.g.*, growth hormone, thyroid stimulating hormone), thyrocalcitonin hormone, parathyroid hormone.

3. **Iodothyronines.** Iodothyronines is group of iodinated aminoacids with a diphenyl ether ring system in the side chain. Thyroxine is the longest and best known of this group.

4. **Steroid Hormones.** Examples : Aldosterone, cortisol, androgens, calcitriol, testosterone, oestrogens and progesterone.

Differences between Hormones and Enzymes

Hormones	*Enzymes*
1. They are produced at one site and are passed by blood to another site for action.	1. They may act at site where they are produced or carried to another site for action.
2. They have low molecular weight.	2. They have very high molecular weight.
3. Hormones may be steriods, proteins, peptides or amino acid derivatives.	3. Enzymes are simple proteins.
4. They are used up in their action.	4. They are not used up in their action.
5. They are effective in low concentration. Their excess or deficiency may cause disorders.	5. They also act in low concentration. However, the rate of enzyme catalyzed reactions steadily increase with an increase in their concentration.
6. They may act slowly or quickly.	6. They act slowly.
7. They may accelerate or retard the specific reactions.	7. They speed up the reactions.
8. Hormone controlled reactions are not reversible.	8. Enzyme controlled reactions are reversible.

Differences between Hormones and Vitamins

Hormones	*Vitamins*
1. Hormones may be steroids, proteins, peptides or amino acid derivatives.	1. They are never proteins but simple organic compounds such as amines, esters, alcohol aldehyde or organic acids.
2. They are effective in low concentration. Their excess or deficiency may cause hormonal disorders.	2. They are needed in small quantity. Excess vitamins are excreted. Their deficiency causes malfunctioning called deficiency diseases or avitaminosis.
3. They are secreted by the animal in its own body.	3. They are rarely synthesized in the body. They are mostly taken with food.
4. Hormones influence the genes to produce specific enzymes required during metabolism.	4. They act as co-enzymes and help enzymes to perform their function.

Differences between Neural and Chemical Coordination

Neural Co-ordination	*Chemical Co-ordination*
1. Information passes as electrical impulses along nerve fibres.	1. Information passes as a chemical substance through the blood and lymph.
2. There is rapid transmission.	2. There is slow transmission.
3. Response is immediate.	3. Response is usually slow.
4. Response is very exact.	4. Response is usually widespread.
5. Response is short lived.	5. Response is long-lasting.

Human Endocrine System (Fig. 22.3)

It includes the following endocrine glands.

1. Thyroid gland

Origin. It develops from the endoderm of the embryo.

Location and structure. The thyroid gland is the **largest** endocrine gland located anterior to the thyroid cartilage of the larynx in the neck. The gland is well supplied with blood vessels. It is bilobed organ. The two lobes are connected by a narrow structure called the **isthmus.** The microscopic structure of the thyroid gland shows **thyroid follicles** composed of **cubical epithelium** and filled with a homogenous material called **colloid.** Small amount of loose connective tissue forms **stroma** of the gland. Besides containing blood capillaries, the stroma contains small clusters of specialized **parafollicular cells** or **'C' cells.** The thyroid gland

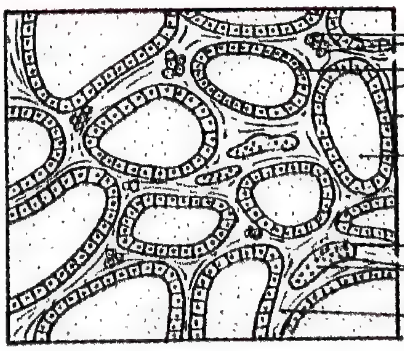


Fig. 22.2. T.S. Thyroid gland.

is the only gland that stores hormones in large quantities for about two months.

Hormones. The thyroid gland secretes three hormones. **Thyroxine (tetraiodothyronine** or T_4), and **tri-iodothyronine** or T_3 are secreted by the thyroid follicular cells. **Thyrocalcitonin** is secreted by the C-cells of the thyroid gland. This gland is stimulated to secrete its hormones by **thyroid stimulating hormone** (also called **thyrotropin**) secreted by the anterior lobe of pituitary gland.

(i) **Thyroxine (T_4) and Tri-iodothyronine (T_3).** T_4 and T_3 contain four and three atoms of iodine respectively, therefore, they are named so. T_3 is secreted in smaller amounts but it is more active and several times more potent than T_4. T_4 is converted to T_3 by removal of one iodine in the liver, kidneys and some other tissues. Since both T_4 and T_3 have similar effects on the target cells, they are generally considered together under the name, **thyroid hormone** (TH).

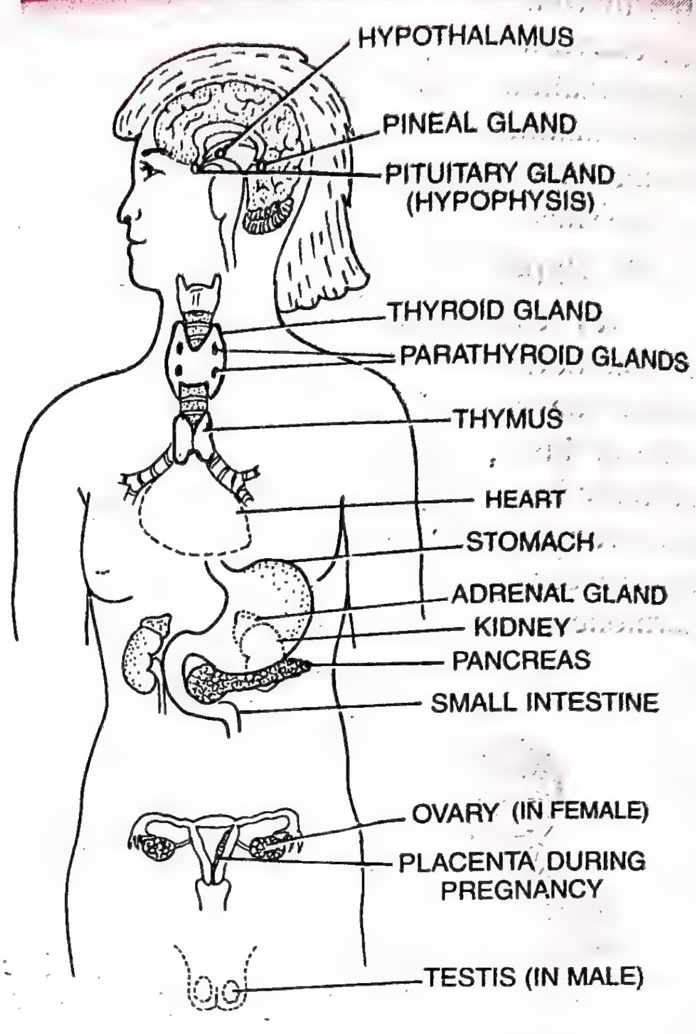


Fig. 22.3. Human endocrine glands.

The thyroid gland is the only gland that stores its hormones in large quantity. T_4 and T_3 are synthesised by attaching iodine to **tyrosine*** aminoacid. The functions of thyroxine (T_4) and tri-iodothyronine (T_3) are as follows.

(a) They regulate the metabolic rate of the body and thus maintain basal **metabolic** rate (BMR).

(b) They stimulate protein synthesis and, therefore, promote growth of the body tissues.

(c) They regulate the development of mental faculties.

(d) As they increase heat production, thus they maintain body temperature.

(e) They help in metamorphosis of tadpole into adult frog. If thyroid gland of the tadpole (larva) is removed, the larva fails to change into an adult.

(f) They increase action of neurotransmitters like adrenaline and noradrenaline.

(ii) **Thyrocalcitonin (TCT).** It is secreted when calcium level is high in the blood. It then lowers the calcium level by suppressing release of calcium ions from the bones. Thus thyrocalciton has an action opposite to that of the parathyroid hormone on calcium metabolism. Thyrocalcitonin is also called calcitonin. It is a peptide which contains 32 amino acids.

Thyroid Disorders

(A) Hyperthyroidism (Hypersecretion of thyroid hormone).

Exophthalmic goitre or **Graves' disease** or **Basedow's disease** or **Parry's disease.** It

*Tyrosine aminoacid forms thyroxine, noradrenaline and adrenaline.

is a thyroid enlargement (goitre) in which the thyroid secretes excessive amount of thyroid hormone. It is characterised by exophthalmia (protrusion of eye balls because of fluid accumulation behind them), loss of weight, slightly rise in the body temperature, excitability, rapid heart beat, nervousness and restlessness.

(B) **Hypothyroidism** (Hyposecretion of thyroid hormone).

(a) **Cretinism.** This disorder is caused by deficiency of thyroid hormone in infants. A cretin has slow body growth and mental development of reduced metabolic rate. Other symptoms of this disorder are slow heart beat, lower blood pressure, decrease in temperature, stunted growth, pot-belly, pigeon chest and protruding tongue and retarded sexual development. This disease can be treated by an early administration of thyroid hormones.

Fig. 22.4. Graves' disease.

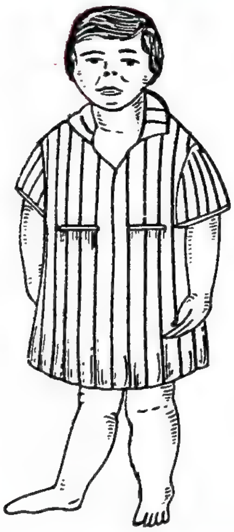


Fig. 22.5. Cretinism.

Fig. 22.6. Myxoedema.

Fig. 22.7. Simple goitre.

(b) **Myxoedema or Gull's disease.** It is caused by deficiency of thyroid hormone in adults. This disease is characterized by puffy appearance due to accumulation of fat in the subcutaneous tissue because of low metabolic rate. The patient lacks alertness, intelligence and initiative. He also suffers from slow heart beat, low body temperature and retarded sexual development. This disease can be treated by administration of thyroid hormones.

(c) **Simple Goitre.** It is caused by deficiency of iodine in diet because iodine is needed for the synthesis of thyroid hormone. It causes thyroid enlargement. It may lead to cretinism or myxoedema. This disease is common in hilly areas. Addition of iodine to the table salt prevents this disease.

(d) **Hashimoto's disease.** In this disease all the aspects of thyroid function are impaired. It is an autoimmune disease in which the thyroid gland is destroyed by autoimmunity.

Differences between Exophthalmic Goitre and Iodine Deficiency Goitre

Exophthalmic Goitre	*Iodine Deficiency Goitre*
1. It is caused due to excess secretion of thyroid hormone.	1. It arises due to deficiency of iodine and thereby less/no secretion of thyroxine.
2. The eyeballs are bulging along with enlargement of thyroid.	2. The eyeballs do not bulge; the thyroid enlarges and is seen as a swelling in the neck.
3. There is higher rate of metabolism, rate of heart beat and blood pressure.	3. There is low rate of metabolism, rate of heart beat and blood pressure.

2. Parathyroid glands

Origin. They develop from the endoderm of the embryo.

Location and Structure. The parathyroid glands consist of four separate glands located on the posterior surface of the lobes of the thyroid gland. The cells of parathyroid glands are arranged in a compact mass and are of two types: small **chief cells** or **principal cells** and large **oxyphil cells** (or **eosinophil cells**). The cells are enclosed by a delicate connective tissue **capsule**. The chief cells are much more numerous than the oxyphil cells. The latter are absent in the young and appear a little before the age of puberty.

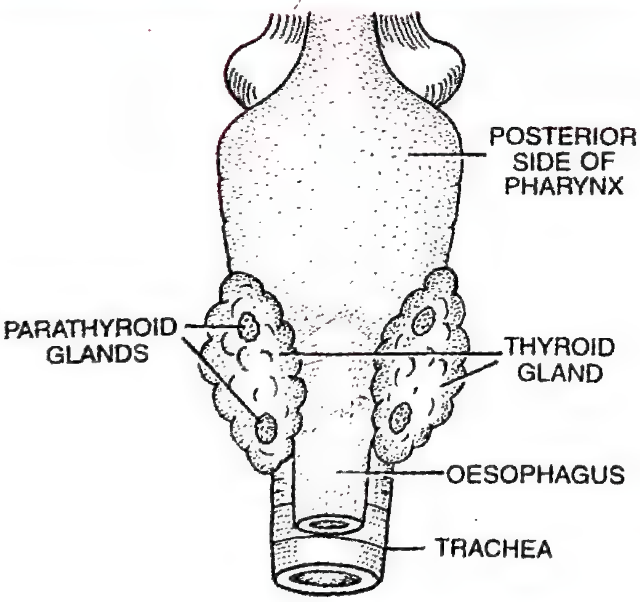


Fig. 22.8. Parathyroid glands lie on the posterior surface of thyroid gland.

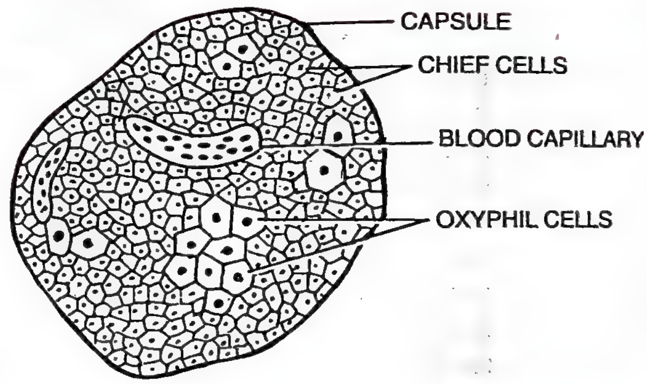


Fig. 22.9. T.S. Parathyroid gland.

Hormone. The chief cells of the parathyroids secrete a hormone called **parathyroid hormone** (PTH) or **parathormone** or also called **Collip's hormone** after the name of its discoverer. This hormone regulates the calcium and phosphate balance between the blood and other tissues. PTH inhibits collagen synthesis by osteoblasts and bone resorption by osteoclasts. It mobilises the release of calcium into the blood from the bones. PTH increases calcium absorption from the intestines. It increases calcium resorption from the nephrons (and inhibits phosphate resorption) of the kidneys. Thus parathormone regulates the metabolism of calcium and phosphate.

Parathyroids are under the **feeding back control** of blood calcium level. A fall in blood calcium stimulates them to secrete parathormone, a rise in blood calcium inbihits parathormone secretion from them. Thus PTH has an effect that opposes the effect of **calcitonin**.

The functions of oxyphil cells are unknown.

Parathyroid Disorders. (i) **Hypoparathyroidism** (deficiency of PTH). It causes the lowering of blood calcium level. This increases the excitability of nerves and muscles, causing cramps and convulsions. Sustained contractions of the muscles of larynx, face, hands and feet are produced. This disorder is called **parathyroid tetany** or **hypocalcaemic tetany.**

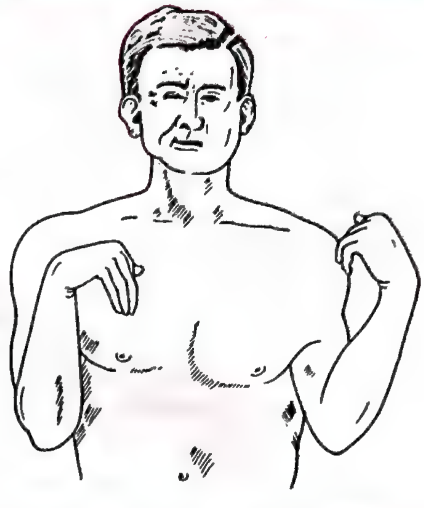


Fig. 22.10. Parathyroid tetany.

(ii) **Hyperparathyroidism** (excess of PTH). Excess of PTH draws more calcium from the bones. It causes demineralisation, resulting in softing and bending of the bones. Some of the bone substance is replaced by cavities that are filled with fibrous tissues. This condition leads to **osteitis fibrosa cystica** or **osteoporosis.** Because bones become deformed, they are easily fractured. Osteoporosis is common in women who have reached menopause (cessation of menstruation). An excess of parathormone also causes calcium to be deposited in the kidneys. Analysis of the content of kidney stones sometimes suggests the presence of a parathyroid tumour.

Differences between Hypoparathyroidism and Hyperparathyroidism

Hypoparathyroidism	*Hyperparathyroidism*
1. It is deficiency of PTH.	1. It is excess of PTH.
2. It is due to accidental damage to the parathyroids or their blood supply during thyroidectomy.	2. It is usually due to formation of a tumour in the parathyroids.
3. There is deficiency of calcium which leads to muscle twitches, spasms and convulsions. This condition is called parathyroid tetany or hypocalcaemic tetany.	3. The bones become soft, deformed and the destroyed bone tissues are replaced by cavities that are filled with fibrous tissues. Such bones are easily fractured. This condition is called osteitis fibrous cystica or osteoporosis.

3. Adrenal or Suprarenal Glands (Glands of Emergency)

Location and Structure. These are paired structures located on the top of the kidneys. Each adrenal gland has two parts external adrenal **cortex** and internal adrenal **medulla**. The cortex is surrounded by a fibrous **capsule**. Both adrenal cortex and medulla have different embryonic origin, structure and functions to be described ahead.

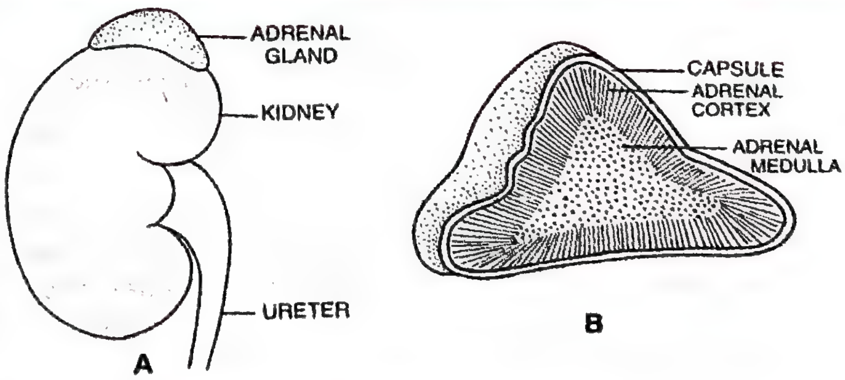


Fig. 22.11. A, Position of adrenal gland.
B, T.S. Adrenal gland.

(A) Adrenal Cortex

Origin. The adrenal cortex is derived from the mesoderm of the embryo.

Structure (Fig. 22.12). The adrenal cortex is subdivided into three zones :

(i) **Zona glomerulosa** (*zona*– belt, *glomerul*– little ball). This is the outer zone that lies just below the capsule. It constitutes about 15% of the gland. Its cells are closely packed and arranged in spherical clusters and arched columns which secrete homones called **mineralocorticoids** because they affect mineral homeostasis.

(ii) **Zona fasciculata** (*fascicul*– little bundle). This is the middle zone which is widest of the three zones. It constitutes about 50% of the gland. It consists of the cells arranged in long, straight columns. The cells of this zone secrete mainly **glucocorticoids**, which are named because they affect glucose homeostasis.

(iii) **Zona reticularis** (*reticul*– network). This is the inner zone that constitutes about 7% of the gland. The cells are arranged in branching cords which secrete **gonadocorticoids** (*e.g.*, androgens that have musculinizing effects).

The cells of the zona fasciculata and zona reticulata contain ascorbic acid (vitamin C).

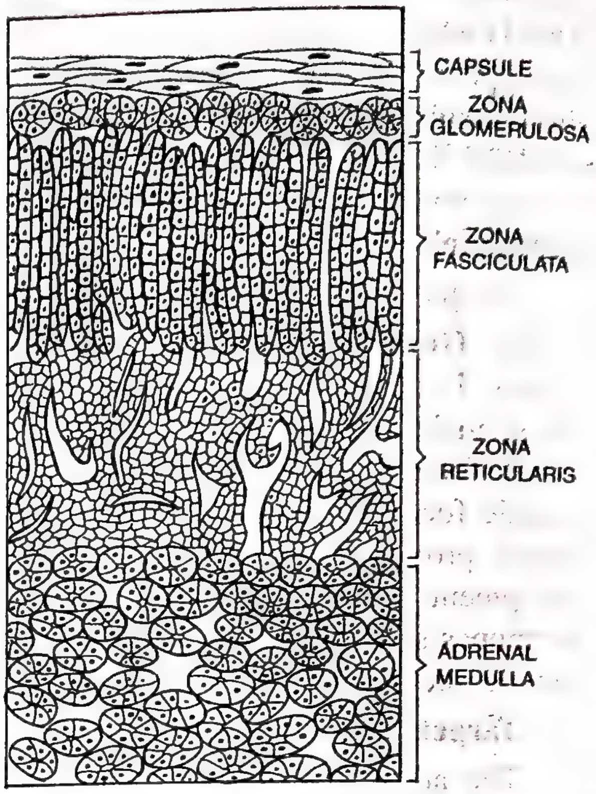


Fig. 22.12. Microscopic structure of adrenal gland.

Hormones. All hormones of adrenal cortex are synthesized from cholesterol. **Corticosteroids** (corticoids—hormones of adrenal cortex) are grouped into three catagories : mineralocorticoids, glucocorticoids and gonadocorticoids.

(i) **Mineralocorticoids**. These hormones are secreted by the cells of zona glomerulosa of adrenal cortex. As the name indicates, they are responsible for the regulation of mineral metabolism. **Aldosterone** (salt-retaining hormone) is the principal mineralocorticoid (90 to 95%) in humans. Like all other hormones of the adrenal cortex, aldosterone is a steroid. Its main function is to regulate the sodium content of the body. It is secreted when the sodium level is low. It acts on the kidneys to cause more sodium to be returned to the blood and more potassium to be excreted. As the sodium concentration in the blood increases, water follows it by osmosis, so the blood volume also increases. Thus the effect of aldosterone is to increase both sodium and water in the blood.

Target cells. Mineralocorticoids act on the cells of the kidneys.

(ii) **Glucocorticoids**. As their name suggests, they affect carbohydrate metabolism, however, they also affect the metabolism of proteins and fats. Glucocorticoids include three main hormones: **cortisol** (= hydrocortisone), **corticosterone** and **cortisone.** Of the three, cortisol is the most abundant (about 95%). It stimulates the liver to synthesize carbohydrates from non-carbohydrates such as amino acids and glycerol. Thus increases level of glucose in the blood. Cortisol also stimulates the degradation of proteins within cells and amino acids in the blood, therefore, increases level of amino acids in the blood. A third effect of cortisol is to stimulate the break-down of fats in adipose tissue and release fatty acids into the blood. Thus cortisol has anti insulin effect. It also helps in reducing pain. Cortisol is **anti-inflammatory**. It retards phagocytic acitivities of WBCs and thus suppresses 'inflammation reaction'. This hormone also reduces the number of mast cells, reducing secretion of histamine. This

is also an anti-infammatory effect. Cortisol is also **"immunosuppressive"**. It suppresses synthesis of antibodies by inhibiting the production of lymphocytes in the lymphoid tissues. That is why, cortisol is used for treatment of allergy. It is also used in transplantation surgery to suppress the formation of antibodies in the body of recipients so that the latter may accept the transplanted organs. This hormone increases RBC count, but decrease the WBC count of blood. It also elevates blood pressure. Cortisol has the capacity to cope with stress. When we are under stress our body secretes cortisol that is why this hormone is called **"stress hormone"**.

Target Cells. Glucocorticoids act on the cells of the liver.

(iii) **Gonadocorticoids** (Sexcorticoids). They are also called sex hormones of adrenal glands. Large quantities of male than female sexcorticoids (sex hormones) are produced. These male sex hormones are called **androgens** which are important in the development of a male foetus. Although the genetic sex is determined by the chromosomes in a fertilized egg, a male foetus develops normal male characteristics only if the foetal gonads and adrenal glands produce sufficient quantities of androgens. Therefore, androgens stimulate the development of male secondary sexual characters like distribution of body hair. Female sex hormones secreted by the adrenal cortex are **oestrogens** which maintain the development of female secondary sexual characters.

Target cells. Gonadocorticoids act on the cells of gonads (testes and ovaries).

The adrenal cortex is essential for life. Its removal or destruction is fatal unless the hormones produced by it are supplimented artificially.

Disorders of the Adrenal cortex. (i) **Addison's disease.** This disease is caused by the deficiency of mineralocorticoids and glucocorticoids. It is also caused by the destruction of adrenal cortex in disease such as tuberculosis. Its symptoms include low blood sugar, low plasma Na^+, high K^+ plasma, increased urinary Na^+, nausea, vomiting, diarrhoea and a bronze-like pigmentation of skin. Severe dehydration is also common in the person suffering from this disease.

(ii) **Cushing's Syndrome*** (Fig. 22.13). It is caused by excess of cortisol which may be due to a tumour of the adrenal cortex. It is characterised by high blood sugar, appearance

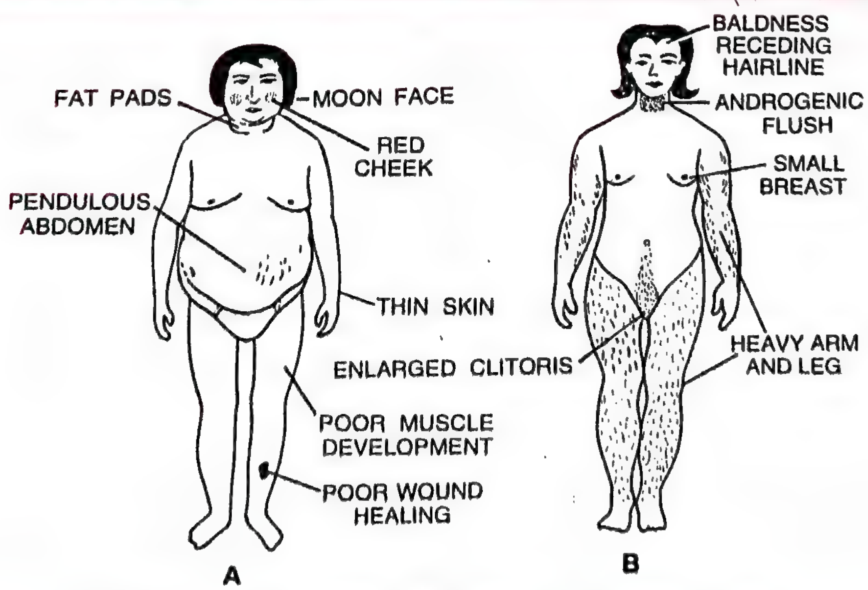


Fig. 22.13. A, Cushing's syndrome. B, Adrenal Virilism.

*Syndrome is a group of signs and symptoms that occur together.

of sugar in the urine, rise in plasma Na^+, fall in plasma K^+, rise in blood volume, high blood pressure, obesity and wasting of muscles of thighs and pectoral and pelvic girdles.

(iii) **Aldosteronism (Conn's Syndrome).** Excessive production of aldosterone from an adrenal cortical tumour causes this disease. Its symptoms include a high plasma Na^+, low plasma K^+, rise in blood volume, high blood pressure and polyurea.

(iv) **Adrenal Virilism** (Fig. 22.13). Appearance of male characters in female is called virilism. Excessive production of male sexcorticoids (androgens) produces male secondary sexual characters like beard, moustache, hoarse voice in woman.

(v) **Gynaecomastia.** It is the development of enlarged mammary glands (breasts) in the males. It is due to excessive secretion of female sex hormones (oestrogens) in males. Decreased testosterone may also lead to gynaecomastia.

(B) Adrenal Medulla

Origin. The adrenal medulla develops from the neuroectoderm of the embryo.

Structure. The adrenal medulla consists of rounded groups of relatively large and granular cells. These cells are modified postganglionic cells of sympathetic nervous system which have lost normal processes and have acquired a glandular function. These cells are called **chromaffin cells** or **phaeochromocytes**. These cells are connected with the preganglionic motor fibres of the sympathetic nervous system. Obviously, the adrenal medulla is simply an extension of the sympathetic nervous system, therefore, these are discussed together as **sympathetico-adrenal system.**

Hormones

The medulla of the adrenal glands secretes two hormones : norepinephrine (noradrenaline) and epinephrine (adrenaline). Norepinephrine and epinephrine are derived from tyrosine aminoacid.

(i) **Norepinephrine (= Noradrenaline).** It regulates the blood pressure under normal condition. It causes constriction of essentially all the blood vessels of the body. It causes increased activity of the heart, inhibition of gastrointestinal tract, dilation of the pupils of the eyes and so forth.

(ii) **Epinephrine (= Adrenaline).** It is secreted at the time of emergency. Hence it is also called **emergency hormone**. It causes almost the same effects as those caused by norepinephrine, but the effects differ in the following respects. First, epinephrine has a greater effect on cardiac activity than norepinephrine. Second, epinephrine causes only weak constriction of the blood vessels of the muscles in comparison with a much stronger constriction that results from norepinephrine. A third difference between the action of epinephrine and norepinephrine relates to their effects on tissue metabolism. Epinephrine probably has several times as great a metabolic effect as norepinephrine.

Target Cells. Both adrenaline and noradrenaline acts on the cells of skeletal, cardiac and smooth muscles and blood vessels and fat cells.

Because of the role of their hormones, the adrenal glands are also called **'glands of emergency'**.

Sympatheticoadrenal System. Stimulation of the sympathetic nerves to adrenal medulla causes large quantities of epinephrine (adrenaline) and norepinephrine (noradrenaline) to be released into the blood circulation and then these hormones are carried to all the tissues of the body. Both the hormones (epinephrine and norepinephrine) and sympathetic nervous system act on the same organs and produce similar effects on them (*e.g.*, accelerates heart beat, raises blood pressure, slows peristalsis, etc.). Since the sympathetic nervous system

and the adrenal medulla function as an integrated system, it is called **sympatheticoadrenal system**.

Adreneline hormone is responsible for "fight or flight response".

Differences between Adrenal Cortex and Adrenal Medulla

Adrenal Cortex	*Adrenal Medulla*
1. It is outer firm part of the adrenal gland.	1. It is central soft part of the adrenal gland.
2. It forms about 75% part of the gland.	2. It forms about 25% of the gland.
3. It is enclosed by a fibrous capsule.	3. It is not enclosed by a fibrous capsule.
4. It develops from the mesoderm.	4. It develops from ectoderm.
5. It comprises three regions or zones (a) outer thin zona glomerulosa. (b) middle thick zona fasciculata and (c) inner thin zona reticularis.	5. It is not differentiated into regions. It consists of chromophil cells. The adrenal medulla is simply an extension of the sympathetic nervous system.
6. It is essential for life. Its destruction causes death.	6. It is not so essential for life. Its destruction does not cause death.
7. It is stimulated to release its hormones by adrenocorticotrophic hormone (ACTH) from the anterior lobe of pituitary gland.	7. It is stimulated to secrete its hormone by nerve impulses reaching through sympathetic nerve fibres.
8. It secretes three groups of hormones : mineralocorticoides glucocorticoides and gonadocorticoides.	8. It secretes two similar hormones : noradrenaline and adrenaline.
9. There is no cooperation between adrenal cortex and sympathetic nervous system.	9. Adrenal medulla and sympathetic nervous system function as an integrated system called sympatheticoadrenal system.

4. Hypothalamus

Origin. Hypothalamus develops from the ectoderm of the embryo.

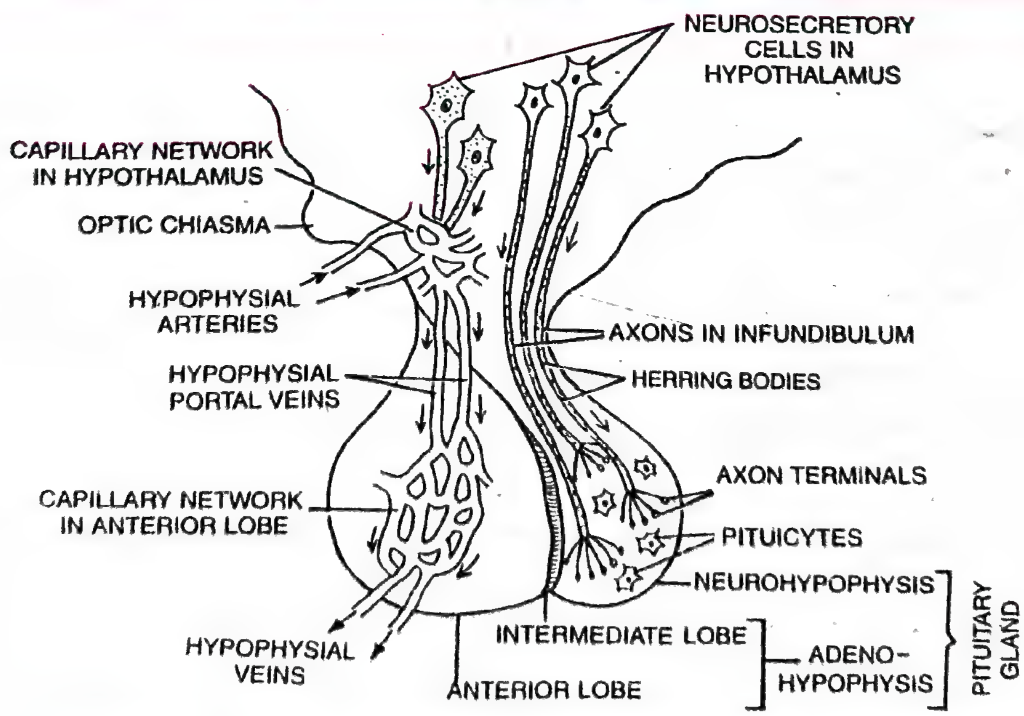


Fig. 22.14. Neurosecretory cells (neurons) of hypothalamus discharging their neurohormones into hypophysial portal veins and into neurohypophysis (posterior lobe) of pituitary gland.

Location and Structure. It lies below or inferior to the thalamus. It provides the anatomical connection between the nervous and endocrine systems. This connection is through the hypophysis (pituitary gland). The hypothalamus is connected to the anterior lobe of pituitary gland by hypophysial portal veins, however, it is connected to the posterior lobe of pituitary gland mainly by axons of neurosecretory cells. The hormones of the hypothalamus influence the functioning of the pituitary gland. The hypothalamus is often called the control centre or **'supreme commander'** of endocrine regulation.

Hormones. Cells in the hypothalamus synthesize atleast nine different hormones. The neurosecretory cells (neurons) of hypothalamus secrete hormones called **neurohormones** (= **releasing factors**) which are summarised below.

(i) **Adrenocorticotropic Releasing hormone** (ARH) or **Corticotropin Releasing Hormone.** It stimulates the anterior lobe of the pituitary gland to secrete its adrenocorticotropic hormone (ACTH).

(ii) **Thyrotropin Releasing Hormone** (TRH). It stimulates the anterior lobe of the pituitary gland to secrete its thyroid stimulating hormone (TSH) or thyrotropin.

(iii) **Growth Hormone-Releasing Hormone** (GHRH). It stimulates the anterior lobe of the pituitary gland to release its growth hormone (GH) or somatotrophin.

(iv) **Growth Hormone-Inhibitory Hormone** (GHIH). This hormone is also called **somatostatin (SS).** It inhibits the secretion of growth hormone from the anterior lobe of the pituitary gland.

(v) **Gonadotropin Releasing Hormone** (GnRH). It stimulates the anterior lobe of the pituitary gland to secrete two gonadotropic hormones: (follicle stimulating hormone (FSH) and luteinising hormone (LH)).

(vi) **Prolactin Releasing hormone** (PRH). It stimulates the anterior lobe of the pituitary gland to secrete its prolactin.

(vii) **Prolactin Inhibitory Hormone** (PIH). It inbihits the secretion of prolactin from the anterior lobe of pituitary gland.

(viii) **MSH Releasing Hormone** (MSHRH). It stimulates the intermediate lobe of the pituitary gland to secrete its melanocyte stimulating hormone (MSH).

(ix) **MSH Inhibitory Hormone** (MSHIH). It inhibits the secretion of melanocyte stimulating hormone from the intermediate lobe of the pituitary gland.

Target Cells. Neurohormones act on the cells of the pituitary gland.

5. Pituitary gland (Hypophysis cerebri) — Master Endocrine gland

Origin. It develops from ectoderm of the embryo.

Location and Structure. The pituitary gland is located just below the hypothalamus. The pituitary gland is situated in a depression the **sella turcica** of sphenoid bone of the skull. The pituitary gland is the *smallest* endocrine gland. It is about 1.3 cm in diameter and weighs about half a gram. The gland is attached to the brain by a stalk the **infundibulum** which is continuous with the **hypothalamus** above. The pituitary gland is formed of two main lobes of *different origin.* These

Fig. 22.15. A pituitary giant stands with a dwarf man and of normal height.

lobes are the much larger **anterior lobe** or **adenohypophysis** or **pars distalis** and the smaller **posterior lobe** or **neurohypophysis** or **pars nervosa.** *Adenohypophysis originates as Rathke's pouch from dorsal wall of stomodaeum in the embryo, but later its connection with the stomodaeum disappears.* The neurohypophysis originates as an outgrowth from the floor of the diencephalon. Thus the pituitary gland is dual in origin (from stomodaeum – foregut and diencephalon). A third lobe, called the **intermediate lobe** or **pars intermedia** is a part of adenohypophysis.

Adenohypophysis comprises about 75% part of the pituitary gland. The **hypophysial portal veins** carry blood containing neurohormones (releasing factors) from the hypothalamus to the adenohypophysis. Neurohypophysis comprises about 25% part of the pituitary gland. The axons of neurosecretory cells (secretory neurons) extend into the neurohypophysis where these axons terminate as **axon terminals.** These terminals are embedded in a neuroglial tissue formed of large and branched cells called **pituicytes.** Obviously *no hormones are synthesized in neurohypophysis* but two hormones, synthesized in the hypothalamic neurosecretory cells remain stored in very small vesicles in the axons and terminals. These vesicles are called **Herring bodies.**

(a) **Hormones of the Anterior lobe**

The anterior lobe of the pituitary gland secretes the following hormones, most of them are **trophic hormones.**

(i) **Growth hormone** (STH or GH) or **Somatotrophin** (*Soma*– body, *trophe*– nourishment). This hormone stimulates growth. Growth hormone promotes protein anabolism, the absorption of calcium from the bowel and the conversion of glycogen to glucose.

Target Cells. Various body cells which undergo growth.

(ii) **Thyroid stimulating hormone** (TSH) or **Thyrotropin**. This hormone controls the growth and activity of the **thyroid gland**. It influences the uptake of iodine, the synthesis of the hormones, **thyroxine** and **tri-iodothyronine** by the thyroid gland and the release of stored hormones into the blood stream.

Target Cells. Cells of thyroid.

(iii) **Adrenocorticotropic hormone** (ACTH). This hormone stimulates the cortex of the **adrenal gland** to produce its hormones.

Target Cells. Cells of adrenal cortex.

(iv) **Prolactin hormone (PRL)** or **Mammotropin hormone** (MTH) or **Luteotropic hormone** (LTH). Prolactin is also called the **"hormone of maternity"** because its main physiological effect is to activate growth of breasts during pregnancy and secretion of mammary glands after child birth. The name luteotrophic hormone (LTH) refers to because it also stimulates the corpus luteum of the ovary to secrete progesterone hormone.

Target Cells. Cells of mammary glands.

(v) **Gonadotropic hormones.** These are as follows : (a) **Follicle-stimulating hormone (FSH).** It stimulates growth of ovarian follicles and their secretion of oestrogens in the female, and spermatogenesis (formation of sperms) in the male.

(b) **Luteinizing hormone** (LH). In female it stimulates the corpus luteum of the ovary to secrete progesterone. In male it activates the Leydig's (interstitial) cells of the testis to secrete androgenes hence it may be called **interstitial cell stimulating hormone** (ICSH) in male.

Target Cells. Cells of gonads (testes and ovaries)

(b) **Hormone of the Intermediate lobe**

The intermediate lobe of the pituitary gland secretes **melanotrophin** or **melanocyte stimulating hormone** (MSH). This hormone causes dispersal of pigment granules in the pigment cells, thereby darkening the colour in certain animals like fishes and amphibians. It is believed that it is associated with the growth and development of melanocytes in man which give colour to the skin.

Target Cells. Melanocytes in skin.

(c) **Hormones of the Posterior lobe**

The secretion of the posterior lobe is known as **pituitrin** and it contains two hormones. (i) Oxytocin or pitocin. (ii) Antidiuretic hormone (ADH) or vasopressin. Once again it is reminded that the posterior lobe of the pituitary gland does not secrete any hormone. Its hormones are secreted in the hypothalamus.

(i) **Oxytocin (OT).** Oxytocin promotes contraction of the uterine muscle and contraction of the myoepithelial cells of the lactating breast, squeezing milk into the large ducts behind the nipple. In late pregnancy the uterus becomes very sensitive to oxytocin. The amount secreted is increased just before and during labour and by sucking of the baby. Because of its role, oxytocin is called "**birth hormone**" and "**milk ejecting hormone**".

Milkmen inject synthetic oxytocin, called **pitocin**, into their cows and the buffaloes to get more milk.

Oxytocin is secreted without the involvement of releasing hormone (RH)

Target Cells. Cells of mammary glands.

(ii) **Antidiuretic hormone (ADH) or Vasopressin or Pitressin.** This hormone has two main functions. (a) **Antidiuretic effect.** It increases the reabsorption of water in the distal convoluted tubule and collecting ducts of the nephrons of the kidneys. As a result, the reabsorption of water from the glomerular filtrate is increased. (b) **Pressor effect.** Involuntary muscles in the walls of the intestine, gall bladder, urinary bladder and blood vessels are stimulated to contract by ADH. Contraction of the walls of the blood vessels raises the blood pressure and this may be its most important pressor effect.

Target Cells. Cells of kidneys.

The pituitary gland is also called **"Master Endocrine Gland"** of body or the **"Chief Executive of Endocrine System"** or **"The Leader of Endocrine Orchestra"** as it secretes the number of hormones (*e.g.*, TSH, ACTH etc.) which regulate the working of other endocrine glands. But it is not proper to call it as master endocrine gland because it is itself under the control of the releasing hormones secreted by the hypothalamus of the brain. Thus the hypothalamus is, in fact, the supreme commander of endocrine regulation.

Pituitary Disorders

(a) **Pituitary Dwarfism.** It is caused by the deficiency of growth hormones (GH) from childhood. It is characterised by small but well porportioned body and sexual immaturity. The **dwarfs** produced by the deficiency of growth hormone are different from those which are formed from the deficiency of thyroid hormone in having normal intelligence.

(b) **Gigantism.** It is caused by excess of growth hormone from early age. It is characterised

by large and well proportioned body. If size of pituitary gland increases, it affects (supresses) optic chiasma and ultimately affects vision.

(c) **Acromegaly** (*Acro*– extremity, *megaly*– large). It is caused by excess of growth hormone after adult size is reached. It is characterised by disproportionate increase in size of bones of face, hands and feet.

(d) **Diabetes insipidus.** It is caused by the deficiency of ADH. It is characterised by excessive dilute urine.

(e) **Simmonds' Disease. Cause** — atrophy or degeneration of anterior lobe of pituitary gland. **Symptoms**— the skin of face becomes dry and wrinkled, premature ageing.

(f) **High blood level of ADH.** It is caused by excessive secretion of ADH. It is characterised by excessively dilute blood and low plasma sodium.

Fig. 22.16. Acromegaly.

Differences between Somatostatin and Somatotropin

Somatostatin (SS)	*Somatotropin (Growth Hormone)*
1. It is secreted by the hypothalamus of the brain, delta cells of islets of Langerhans in the pancreas and argentaffin cells of the digestive tract.	1. It is secreted by the anterior lobe of the pituitary gland.
2. It inhibits the secretion of growth hormone (somatotropin) from the anterior lobe of the pituitary gland. It also suppresses the release of other hormones from the pancreas and digestive tract.	2. It stimulates the growth of the body.

Differences between Somatostatin and Somatomedin

Somatostatin (SS)	*Somatomedin*
1. As stated above it is secreted by hypothalamus, pancreas and digestive tract.	1. It is synthesized in the liver and probably in the kidney.
2. Its functions are given above.	2. It is capable of stimulating certain anabolic processes in bone and cartilage, such as synthesis of DNA, RNA and protein and the sulfation of mucopolysaccharides. Its secretion and/or biological activity is known to be dependent on growth hormone (somatotropin).

Differences between Follicle stimulating hormone and Luteinizing hormone

Follicle stimulating hormone	*Luteinizing hormone*
1. It controls the development of tissues in ovary and testis and gametogenesis.	1. It controls the secretion of sex hormones— testosterone in males and progesterone in females.
2. It stimulates secretion of oestrogen and controls the first half of menstrual cycle in females.	2. It controls the ovulation and the second half of menstrual cycle in females.

Differences between Gigantism and Acromegaly

Gigantism	*Acromegaly*
1. It is caused due to excess secretion of growth hormone during growth period. 2. It is characterized by large and well proportional body.	1. It is caused due to excess secretion of growth hormone after adolescence. 2. It is characterized by disproportionate increase in size of bones of face, hands and feet.

Differences between Cretinism and Dwarfism

Cretinism	*Dwarfism*
1. It is a disorder caused in children due to deficiency or hyposecretion of thyroid hormone. 2. The rate of metabolism, heart rate and blood pressure are low.	1. It is a disorder caused in children due to hyposecretion of growth hormones during growth period. 2. Growth of body cells, bones and muscles is retarded and there is less ATP formation.

6. Pineal Gland (Epiphysis)

Pineal gland has a mass of 0.1—0.2 g.

Origin. It develops from the ectoderm of the embryo.

Location and Structure. The pineal gland is located between the cerebral hemispheres, where it protrudes from the roof of the third ventricle. The pineal gland is a small rounded body which consists of **pineal cells** and supporting glial cells.

Hormone. Though the function of the gland is still the subject of current research, it is known to secrete **melatonin hormone**, also called the "sleep hormone", because it promotes sleep. Its secretion increases in dim light and decreases in bright light. Melatonin concentration in the blood appears to flow a diurnal (day-night) cycle as it rises in the evening and through the night and drops to a low around noon. Because of this light mediated response, the pineal gland may act as a kind of **"biological clock"** which may produce circadian rhythms (variations following a 24 hour cycle). Melatonin lightens skin colour in certain animals. In mammals melatonin possibly acts as an inhibitory factor for sexual maturation.

Serotonin, a neurotransmitter found in other locations in the brain, is also found in the pineal gland. Research evidence is accumulating to support the idea that the pineal gland may be involved in regulating cyclic phenomena in the body.

In man the pineal gland starts to calcify at about the time of puberty. Such calcium deposits are called the **brain sand.** There is no evidence that the presence of brain sand is an indication of degeneration. In fact, the presence of brain sand may indicate increased secretory activity.

7. Thymus

At birth thymus commonly weighs between 10 and 15 gm. It continues to grow up to the age of puberty when its weight ranges between 30 and 40 gm. Thereafter it generally progressively diminishes in size undergoing gradual atrophy and replacement by fat so that after mid-adult life it may weigh only about 10 gm. Disappearance of thymus causes ageing.

Origin. It is derived from the endoderm of the embryo.

Location and Structure. The thymus gland is located in the mediastinum between the sternum and aorta. It is a soft, pinkish, bilobed mass of lymphoid tissue. It is a prominent gland at the time of birth but it gradually atrophies in the adult.

Hassall's corpuscles (macrophages) are spherical or oval bodies present in the thymus. They are phagocytic in function.

Hormone. Thymus secretes a hormone named **thymosin** which stimulates the development of certain kinds of white blood cells involved in producing immunity. It also hastens attainment of sexual maturity.

8. Kidneys

Origin. They develop from the mesoderm of the embryo.

The kidneys secrete three hormones : renin, erythropoetin and calcitriol.

(i) **Renin.** Whenever the rate of ultrafiltration falls, the cells of their **juxtaglomerular complex** secrete and release into blood a compound named **renin.** The latter is proteolytic enzyme. Its some properties are like hormone. It acts upon a plasma-protein, **angiotensinogen,** separating a compound, called **angiotensin–II** from it. Angiotensin–II accelerates heart beat and constricts arterioles, thereby increasing blood pressure. This enhances the rate of ultrafiltration. Simultaneously, the angiotensin–II stimulates adrenal cortex to secrete aldosterone, and enhances water and sodium reabsorption from nephrons. These factors also elevate blood pressure.

(ii) **Erythropoietin.** The oxygen shortage stimulates the kidney cells to secrete a hormone named **erythropoietin** (a circulating glycoprotein) into the blood. Erythropoietin stimulates the bone marrow to increase the production of RBCs.

(iii) **Calcitriol.** Calcitriol is the active form of vitamin D. It promotes absorption of Ca^{2+} and phosphorus in the small intestine and accelerates bone formation.

9. Pancreas

Origin. It is derived from the endoderm of the embryo.

Location and Structure. The pancreas lies inferior to the stomach in a bend of the duodenum. It is both an exocrine and an endocrine gland. A large pancreatic duct runs through the gland, carrying enzymes and other exocrine digestive secretions from the pancreatic acinar cells to the small intestine. The tissue of the pancreas has in addition to the acinar cells, groups of cells called **islets of Langerhans,** after the name of their discoverer (1869). These produce endocrine secretions. Four kinds of cells have been identified in the islets. (i) **Alpha cells** (about 15%) produce glucagon. Alpha cells are also called **A-cells.** (ii) **Beta cells** (about 65%) produce insulin. Beta

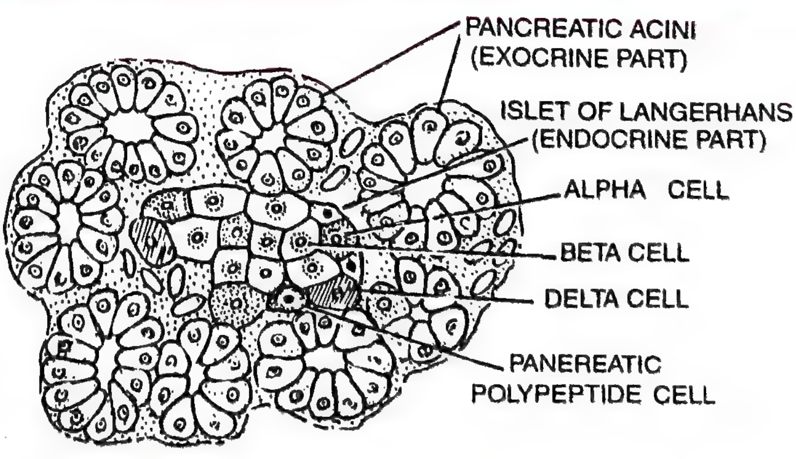


Fig. 22.17. Physiological anatomy of the pancreas.

cells are also called **B-cells.** (iii) **Delta cells** or **D-cells** (about 5%) produce **somatostatin** (SS), and (iv) **Pancreatic Polypeptide cells** or **PP cells** or **F-cells** (15%), produce pancreatic polypeptide (PP). Beta cells are usually found towards the middle of the islet, the alpha cells towards the periphery of the islet and Delta (D) and F-cells are found scattered.

Hormones of Pancreas and their Role

(i) **Glucagon.** It stimulates the liver to convert stored glycogen into glucose. Glucagon is also called an "anti-insulin" hormone.

Target Cells. Glucagon acts on the cells of the liver and adipose tissue.

(ii) **Insulin.** (a) It is antagonistic to glucagon. Insulin converts glucose into glycogen in the liver and muscles.

(b) It promotes protein synthesis in tissue from amino acids.

(c) Insulin reduces catabolism of proteins. It is an **anabolic hormone.**

(d) It increases the synthesis of fat in the adipose tissue from fatty acids.

(e) Insulin reduces the breakdown and oxidation of fat.

Target Cells. Insulin acts on the cells of the liver muscles and adipose tissue.

Alloxan and **Cobalt chloride** are compounds widely used by scientists to study cell physiology of islets of Langerhans. Alloxan is used to destroy the beta cells while cobalt chloride to destroy alpha cells of the islets of Langerhans.

(iii) **Somatostatin (SS).** The same substance as growth inhibiting hormone from the hypothalamus, is produced not only by the pancreas and hypothalamus but also by some cells of the digestive tract. One of the actions of somatostatin seems to suppress the release of other hormones from the pancreas. It also appears to suppress the release of hormones from the digestive tract.

Target Cells. Both somatostatin and pancreatic polypeptide act on the cells of the pancreas.

(iv) **Pancreatic Polypeptide** (PP). It appears that pancreatic polypeptide inhibits the release of digestive secretion of the pancreas.

Both somatostatin and pancreatic polypeptide are relatively newly discovered hormones of the pancreas, and both are still being studied.

Disorders of the Pancreas

(i) **Diabetes mellitus** (Hyperglycemia). The most common endocrine disorder of the pancreas is the diabetes mellitus, now recognized to exist in two forms— insulin-dependent and non-insulin-dependent. The **insulin-dependent diabetes mellitus** (IDDM) is caused by a failure of the Beta-cells to produce adequate amount of insulin while the **non-insulin-dependent diabetes mellitus** (NIDDM) appears to involve failure of insulin to facilitate the movement of glucose into cells. In both disorders the blood glucose concentration is elevated above the normal range. Some of the glucose is excreted in the urine, and water follows the glucose, causing excessive urination and dehydration of body tissues. This causes excessive thirst (**polydipsia**). The cells are unable to utilize glucose and other carbohydrates for energy production. They utilize their proteins for it. The person becomes very weak. Degradation of fats increases, producing ketone bodies (**ketosis**). The latter are acidic and poisonous. Blood cholesterol level rises. Healing power is impaired. Administration of insulin lowers the blood-glucose level. It gives relief to the patient. A tendency towards non-insulin-dependent diabetes appears to be inherited as an autosomal recessive characteristic.

Differences between Type I and Type II Diabetes	
IDDM (Type I)—Juvenile Diabetes	*NIDDM (Type II)*
1. Onset less than 20 years. 2. Normal weight. 3. Ketoacidosis common. 4. Severe insulin deficiency. 5. Beta-cell depletion.	1. Onset more than 30 years. 2. Obese. 3. Ketoacidosis rare. 4. Relative insulin deficiency. 5. Mild beta-cell depletion.

(ii) **Hypoglycemia.** It occurs when the blood glucose level falls below normal. Theoretically, it may be caused by an excess of insulin, a deficiency of glucagon, or a failure of the secretion of the two hormones to completely regulate the blood sugar. Some individuals have been found to have few or no Alpha cells and thus are deficient in glucagon, whereas others produce excess quantities of insulin usually because of a tumour of the beta cells. The presence of excess insulin is more correctly referred to as hyperinsulinism. Symptoms of hypoglycemia include weakness, profuse sweating, irritability, confusion, unconsciousness and convulsions. It needs urgent intake of sugar or glucose.

Differences between Hyperglycemia and Hypoglycemia	
Hyperglycemia	*Hypoglycemia*
1. It is due to deficiency of insulin. 2. Its symptoms are high blood glucose level, breakdown of muscle tissue and tiredness.	1. It is due to excess of insulin. 2. Its symptoms are low blood glucose level, hunger, sweating, irritability and double vision.

Differences between Diabetes mellitus and Diabetes insipidus	
Diabetes mellitus	*Diabetes insipidus*
1. It is due to deficiency of insulin.	1. It is due to deficiency of ADH.
2. It is, thus a pancreatic disorder because insulin is secreted in the pancreas.	2. It is, thus a hypothalamic disorder because ADH is secreted in the hypothalamus.
3. The blood sugar becomes high and glucose appears in urine.	3. The blood glucose is normal and glucose does not appear in urine.
4. There is high blood cholesterol and ketone body formation.	4. There is no such phenomenon.
5. Its symptoms are excessive urine production, excessive thirst and excessive eating.	5. Its symptoms are excretion of large amounts of urine, thirst and dehydration.

10. Gonads

Origin. They develop from the mesoderm of the embryo.

The gonads are the sex glands; the ovaries and the testes. They produce ova and sperms respectively but also secrete hormones.

(a) **Ovaries**. In the female the ovaries are located in the pelvic cavity in close proximity to the oviducts and the uterus. The hormones produced by the ovaries include oestrogens, progesterone, relaxin and inhibin/actin.

(i) **Oestrogens.** These are secreted by the cells of Graafian (ovarian) follicles. **Estradiol** is the principal feminizing oestrogen. It stimulates the development of female secondary sex characteristics during puberty and maintains them through the reproductive years of adult life. It also stimulates maturation of ova (in the ovaries) and development of the uterine epithelium and the mammary glands.

(ii) **Progesterone.** It is secreted by the **corpus luteum** of the ovary. It stimulates further development of the uterine epithelium and mammary glands. It is also required for the formation of the placenta and for the maintenance of pregnancy. Both estradiol and progesterone are required for ovulation.

(iii) **Relaxin.** It is secreted by the corpus luteum only during the later stages of pregnancy and helps to soften ligaments, especially those that hold the pubic symphysis together. It may also affect other ligamets, *e.g.*, if it affects a woman's foot ligaments, she may experience an increase in shoe size following pregnancy.

(iv) **Inhibin/Actin.** Inhibin/actin is secreted by the corpus luteum. Inhibin hormone inhibits and actin hormone activates the FSH and GnRH production.

(b) **Testes.** A pair of testes is situated in the scrotum of male. The connective tissue present between the seminiferous tubules in a testis contains small clusters of endocrine cells called **interstitial cells** or **Leydig's cells**. These cells secrete various **male sex hormones** called **androgens**. The principal androgen is **testosterone**.

(i) Functions of Testosterone

(a) It stimulates the growth and development of male secondary sex organs like the seminal vesicles, prostate and penis. It also helps to maintain their normal functions. Because these organs do not produce gametes (sperms) and only help in reproduction are, therefore, called secondary sex organs.

(b) This hormone also stimulates the development of the male secondary sexual characters like beard, moustache and low-pitch male voice in man.

(c) Testosterone also stimulates the formation of sperms in the seminiferous tubules of the testes.

(d) This hormone promotes the growth of many body tissues such as bones and muscles. It is due to this fact that male has a higher stature than the female.

(ii) Function of inhibin/Actin

Inhibin/actin is secreted by the sustentacular cells of the seminiferous tubules of the testes. Inhibin hormone inhibits and actin hormone activates the FSH production from anterior lobe of pituitary gland.

Disorders of the Gonads

Hypogonadism. Inadequate gonadal function is called hypogonadism. It is due to defects in, or injury to the hypothalamus, the pituitary gland, or the testes or ovaries. It includes male hypogonadism and female hypogonadism.

(a) **Male Hypogonadism.** It is due to the deficiency of androgens— male sex hormones (hypofunction of Leydig's cells), deficiency of sperm formation (hypofunction of Sertoli cells) or both, before puberty. As a result male secondary sexual characters and musculature do not develop.

(b) **Female Hypogonadism.** It is due to deficiency of oestrogens (female sex hormones) pituitary gonadotropins (LH, FSH or both) or can represent primary ovary failure. It results in the lack of development of female secondary sexual characters.

Precocious Puberty. Early maturation of ovaries and testes with production of ova before the age of 9 years in girls or sperms before 10 years in boys is called **sexual precocity.** The causes of sexual pseudoprecocity are excess of sex hormones from the adrenal cortex, testes, ovaries or from other sources, including extragonadal tumours.

(a) **Sexual pseudoprecocity in boys.** It occurs due to excess of testosterone produced by tumours of the testes or adrenal glands. Such boys are characterized by enlargement of penis, masculinisation, early appearance of pubic and axillary hair, faster body growth, etc.

(b) **Sexual pseudoprecocity in girls.** It occurs due to excess of oestrogens secreted by tumours of ovaries and adrenal glands. Such girls are characterized by breast formation, early appearance of pubic hair. However, the maturation and discharge of ova do not occur.

Eunuchoidism. Failure of testosterone secretion causes eunuchoidism. A eunuch has (a) undeveloped and non-functional secondary sex organs like prostrate, seminal vesicles and penis, (b) lacks external sex characters such as beard, moustache and low pitch voice and (c) does not produce sperms.

Gynaecomastia (Gr. *gyne–* woman, *mastos–* breast). Excessive development of male mammary glands is called gynaecomastia. Sometimes they secrete milk. It results when the secretion of oestrogens is more than androgens. In neonate (new born) and during puberty, gynaecomastia is caused by temporary increase in circulating oestrogens. Deficiency of testosterone in later life may also cause gynaecomastia.

11. Gastro-intestinal Tract

Origin. It develops from the endoderm of the embryo.

Inner most layer of the wall of the alimentary canal is called mucosa. Certain cells of the mucosa of the stomach and intestine secrete important hormones.

(a) **Stomach.** The mucosa of the pyloric region of the stomach synthesizes, stores and secretes the hormone **gastrin.** This hormone acts on the gastric glands and stimulates the secretion of hydrochloric acid and pepsinogen.

(b) **Intestine.** It secretes the following hormones :

(i) **Secretin.** It is secreted by the intestinal mucosa of duodenum and jejunum. It acts on the exocrine part of pancreas and stimulates secretion of water and bicarbonate ions. It increases secretion of bile. Probably, it also retards intestinal peristalsis. Secretin also inhibits the secretion and movements of the stomach. *Secretin was the first hormone discovered by scientists.*

(ii) **Cholecystokinin-pancreozymin (CCK-PZ).** This hormone is secreted by the mucosa of entire small intestine. The actions of cholecystokinin and pancreozymin were discovered independently. But it has been discovered that both hormones have similar effects and hence it is considered one hormone. As the name suggests CCK-PZ has two main functions. The word cholecystokinin is derived from three roots : *chol* meaning bile, *cyst* meaning bladder, and *kinin* meaning to remove. The word pancreozymin is derived from pancreas and zymin, which means enzyme producer. This hormone stimulates the gall bladder to release the bile and also stimulates the pancreas to release its enzymes.

(iii) **Gastric Inhibitory Peptide–GIP or Enterogastrone** . It is secreted by duodenal mucosa that inhibits gastric secretion and contractions.

(iv) **Duocrinin.** This hormone is also secreted by duodenal mucosa. It stimulates the Brunner's glands to release mucus and a few enzymes into the intestinal juice.

(v) **Enterocrinin.** It is also secreted by duodenal mucosa. It stimulates the crypts of Lieberkuhn to secrete the enzymes in the intestinal juice.

(vi) **Vasoactive Intestinal Peptide** (VIP). It is secreted by the small intestine. It dilates peripheral blood vessels of the small intestine and inhibits gastric acid secretion.

(vii) **Villikinin.** It is secreted by the mucosa of entire small instestine. It accelerates the movement of intestinal villi to facilitate the absorption of food in the small intestine.

(viii) **Somatostatin (SS).** Somatostatin secreted by the delta cells of Langerhans of pancreas inhibit the secretion of glucagon by alpha cells and insulin by beta cells. Somatostatin produced by argentaffin cells of gastric and intestinal glands supresses the release of hormones from the digestive tract.

(ix) **Pancreatic Polypeptide (PP).** It is secreted by pancreatic polypeptide cells of islets of Langerhans. It inhibits the release of pancreatic juice from the pancreas.

12. Placenta

Placenta is the intimate connection between the foetus and the uterine wall of the mother to exchange the materials. *Placenta is a temporary endocrine gland.* During pregnancy the placenta provides for the exchange of nutrients and wastes between the mother and the developing foetus. It also has some endocrine functions. It secretes some hormones like **oestrogens, progesterone, human chorionic gonadotropin** (HCG), **human chorionic somatomammotropin–** HCS (formerly known as human placental lactogen), **chorionic thyrotropin, chorionic corticotropin** and **relaxin.** Oestrogens and progesterone have the same roles as in the nonpregnant state. However, the placental progesterone also checks contraction of uterine muscles and thus helps to maintain pregnancy. HCG stimulates progesterone release from the corpus luteum and maintains it. Presence of HCG in urine indicates pregnancy. Human choronic somatomammotropin stimulates the growth of mammary glands. Placental relaxin causes relaxation of the ligaments of pubic symphysis and towards the termination of pregnancy it softens and widens the opening of the cervix (lower part of uterus) for easy child birth (parturition).

Other Endocrine Glands

1. **Heart.** The cells, called **cardiocytes** of atria of the heart secrete peptide hormone, called **atrial natriuretic factor** (ANF) in response to an increased return of the deoxygenated (venous) blood. ANF inhibits the release of renin from juxtaglomerular apparatus (JGA) and thereby, inhibits NaCl reabsorption by the collecting duct and reduces aldosterone release from the adrenal gland.

2. **Liver.** The liver produces a protein angiotensinogen which is changed to angiotensin II by an enzyme **renin** secreted by the juxtaglomerular apparatus of the nephrons in the kidney. Angiotensin stimulates the adrenal cortex to produce aldosterone. *Renin works as hormone.*

3. **Skin.** Vitamin D is synthesized in skin epidermis from cholesterol-derived compounds in the presence of sunglight. As stated earlier vitamin D exists in two forms : calciferol or D_2 and cholecalciferol or D_3. Cholecalciferol is more important. It circulates in the blood. Calcitriol is active form of D_3. It increases absorption of calcium and phosphorus from chyme in the small intestine and accelerates bone formation. It is, therefore, required for growth of body and bone formation. Its deficiency causes **rickets** in children and **osteomalacia** in adults.

Eicosanoids (Local Hormones)

Eicosanoids (*eicos*– twenty forms; *oid*– resembling) are derived from the 20-carbon fatty acid— **arachidonic acid**. The eicosanoids are important *local hormones*. The two major types of eicosanoids are **prostaglandins** and **leukotrienes.**

Prostaglandins (PGs). Because they were first found in semen (which is produced partly by the prostate gland), they were named prostaglandins. These are secreted by many organs (*e.g.*, kidneys, gonads, seminal vesicles, thymus, brain, etc.). Traces of prostaglandins are sufficient to cause contraction of smooth muscles. Prostaglandins of seminal vesicles mix with semen. When semen is ejected into the female's vagina prostaglandins contract uterine muscles to facilitate ascending of sperms into the Fallopian tubes. Synthetic prostaglandins are now used for birth control, for inducing labour pains, abortion, cure of asthma, etc. Although the prostaglandins behave like hormones yet they do not meet the requirements of true hormones for two reasons. First they are not produced by distinct glands. Second, they are metabolized so rapidly after they are released that they cannot travel in the blood for any significant distance. Prostaglandins are derivatives of fatty acids.

Leukotrienes (LTs). Leukotrienes are the mediators of allergic response. They also promote responses during inflammation. The release of leukotrienes is increased when some allergic agents combine with antibodies like IgE. The leukotrienes cause bronchiolar constriction, arteriolar constriction, vascular permeability and attraction of neutrophils and eosinophils towards the site of inflammation.

Mechanism of Hormone Action

Hormones are of mainly two types— water soluble (*e.g.*, amino acid derivatives, peptides and protein hormones) and lipid soluble (*e.g.*, steroid hormones). Water soluble hormones require extracellular receptors that generate second messengers (*e.g.*, cAMP) for carrying out their activity. Lipid soluble hormones can pass through cell membranes and directly enter the cells.

1. Mode of Protein Hormone Action through Extracellular Receptors

(i) **Formation of Hormone Receptor Complex.** Every hormone has its own receptor. The number of receptors for each hormone varies. Insulin receptors for most cells is less than 100 but for some liver cells their number may be more than 1,00,000. The molecules

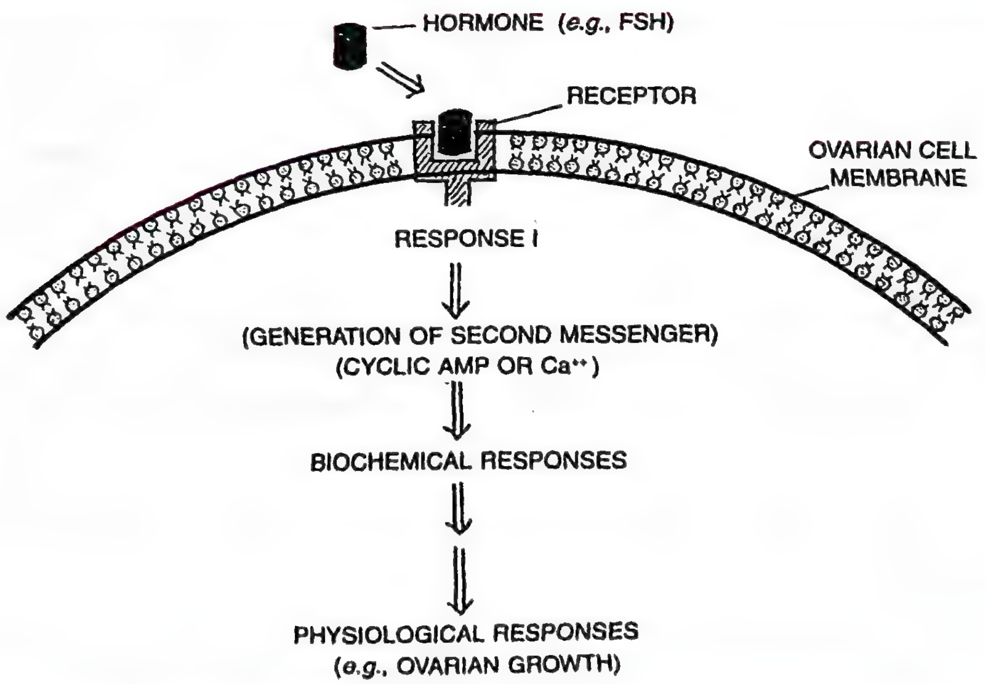


Fig. 22.18. Diagrammatic representation of mechanism of protein hormone action.

of amino acid derivatives, peptides or polypeptide protein hormones bind to specific receptor molecules located on the plasma membrane to form the **hormone receptor complex.**

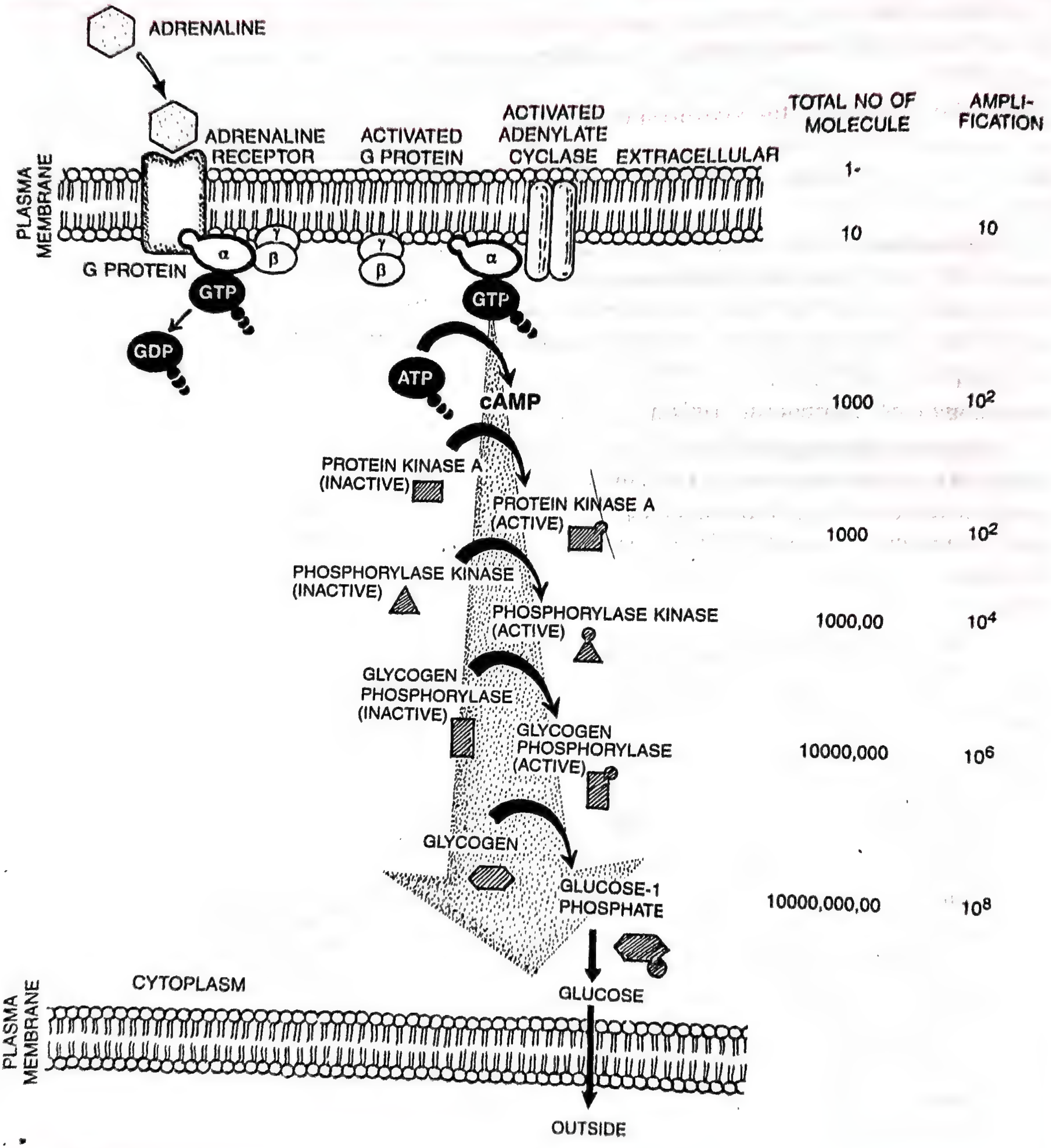


Fig. 22.19. Mode of hormone action through the extracellular receptor and amplification.

(ii) **Formation of Secondary Messengers—the Mediators.** The hormone-receptor complex does not directly stimulates **adenyl cyclase** present in the cell membrane. It is done through a transducer **G protein. Alfred Gilmans** *has shown that the G protein is a peripheral membrane protein consisting of* $\propto$, β *and* γ *subunits* (Fig 22.19). It interconverts between

a GDP form and GTP form. In muscle or liver cells, the hormones such as adrenaline bind receptor to form the hormone-receptor complex in the plasma membrane. The hormone-receptor complex induces the release of GDP from the G protein. The α- subunit bearing GTP separates from the combined β and γ subunits. The β and γ subunits do not separate from each other. The activated β and γ subunits of G protein activate adenyl cyclase. The activated adenyl cyclase catalyses the formation of cyclic adenosine monophosphate (cAMP) from ATP.

The hormone is called the **first messenger** and cAMP is termed the **second messenger**.

$$\text{ATP} \xrightarrow[\text{adenyl cyclase + Mg}^{++}]{\text{Activated}} \text{cAMP + PPi}$$

The hormones which interact with membrane-bound receptors normally do not enter the taget cell, but generate second messengers (*e.g.*, cAMP). Besides, cAMP, certain other intracellular second messengers are cyclic guanosine monophosphate (cGMP), diacyl-glycerol (DAG), inositol triphosphate (IP_3) and Ca^{++} responsible for amplification of signal.

Earl W. Sutherland Jr (1915–1974) discovered cAMP in 1965. He got Nobel prize in physiology or medicine in 1971 for his discovery, "Role of cAMP in hormone action".

(iii) **Amplification of Signal.** Single activated molecule of adenyl cyclase can generate about 100 cAMP molecules. Four molecules of cAMP now bind to inactive protein-kinase complex to activate protein-kinase A enzyme. Further steps as shown in Fig. 22.19 involve **cascade effect**. In cascade effect, every activated molecule in turn activates many molecules of inactive enzyme of next category in the target cell. This process is repeated a number of times.

In the cytoplasm a molecule of protein kinase A activates several molecules of phosphorylase kinase. This enzyme changes inactive form of glycogen phosphorylase into active one. Glycogen phosphorylase converts glycogen into glucose-1 phosphate. The latter changes to glucose. As a result single molecule of adernaline hormone may lead to the release of 100 million glucose molecules within 1 to 2 minutes. This increases the blood glucose level.

(iv) **Antagonistic Effect.** The effect of hormones which act against each other are called antagonistic effects. Many body cells use more than one second messenger. In heart cells cAMP acts as a second messenger that increases muscle cell contraction in response to adrenaline, while cGMP acts as another second messenger which decreases muscle contraction in response to acetylcholine. Thus the sympathetic and parasympathetic nervous systems achieve antagonise effect on heart beat. Another example of antagonistic effect is of insulin and glucagon. Insulin lowers blood sugar level and glucagon raises blood sugar level.

(v) **Synergistic Effect.** When two or more hormones complement each other's actions and they are needed for full expression of the hormone effects are called synergistic effects. For example, the production and ejection of milk by mammary glands require the synergistic effects of oestrogens, progesterone, prolactin and oxytocin hormones.

2. Mode of Steroid Hormone Action through Intracellular Receptors (Fig. 22.20)

Steroid hormones are lipid-soluble and easily pass through the cell membrane of a target cell into the cytoplasm. In the cytoplasm they bind to specific **intracellular receptors** (proteins) to form a hormone receptor complex that enters the nucleus. In the nucleus, hormones which interact with intracellular receptors (*e.g.*, steroid hormones, iodothyromines, etc.) mostly regulate gene expression or chromosome function by the interaction of hormone-receptor complex with the genome. Biochemical actions result in physiological and

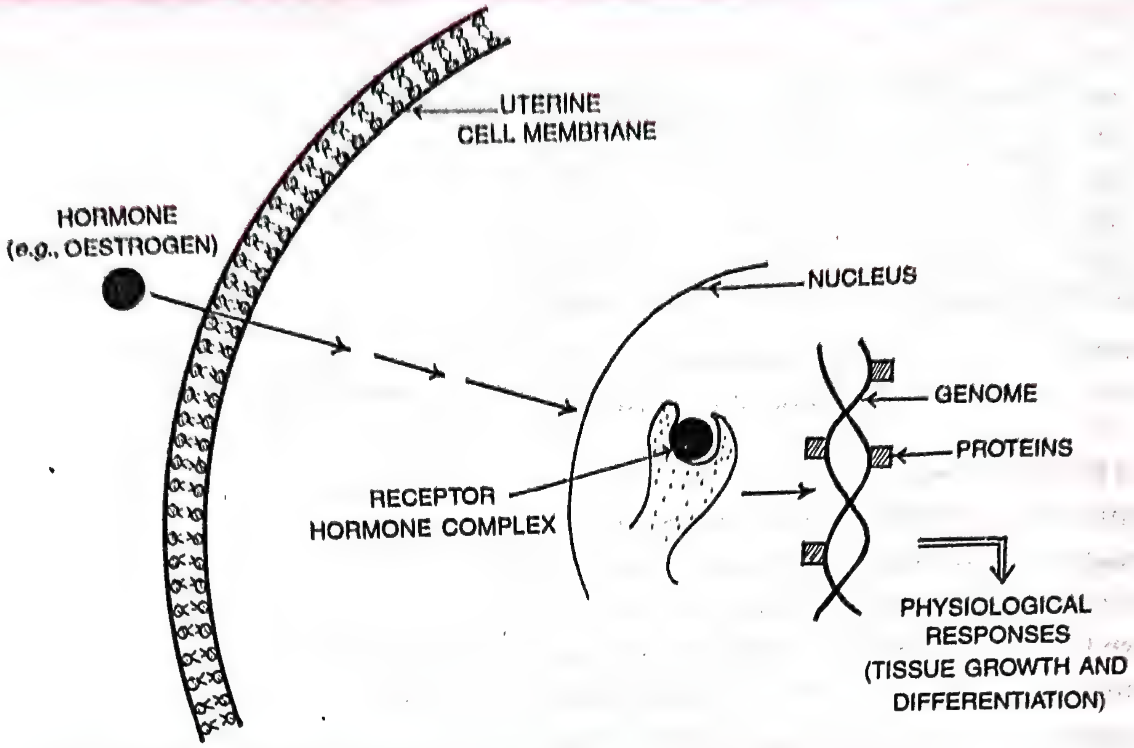


Fig. 22.20. Diagrammatic representation of the mechanism of Steroid hormone.

developmental effects (tissue growth and differentiation, etc). Infact the hormone receptor complex binds to a specific regulatory site on the chromosome and activates certain genes (DNA). The activated gene transcribes mRNA which directs the synthesis of proteins and usually enzymes in the cytoplasm. The enzymes promote the metabolic reactions in the cell. The actions of lipid soluble hormones are slower and last longer than the action of water-soluble hormones.

Role of Hormones as Messengers and Regulators (Role of Hormones in Homeostasis)

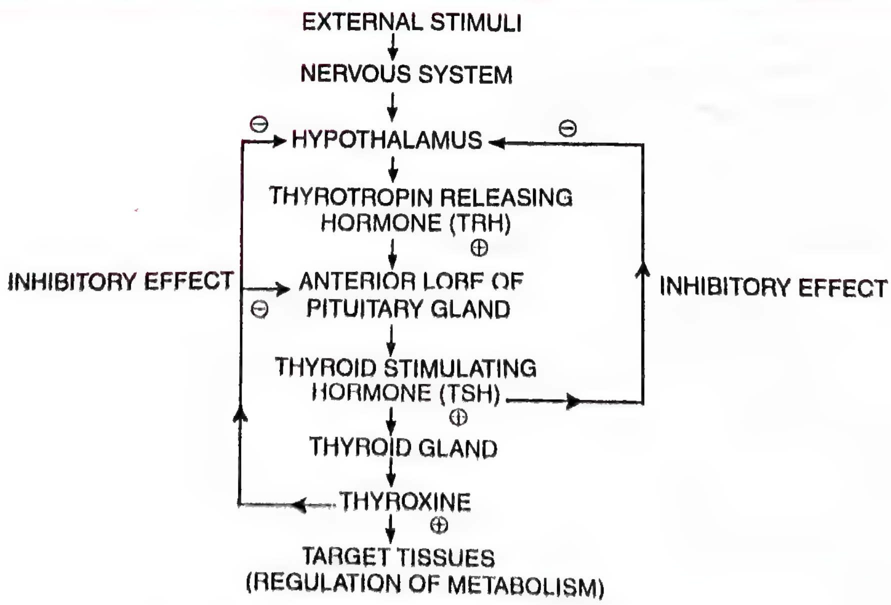


Fig. 22.21. Feed back control involving the hypothalamus, anterior lobe of pituitary gland, thyroid gland and target tissues.

Hormones as Messengers [Hypothalamo-hypophysial (pituitary) Axis]. Hypothalamus is a part of the fore brain. Its hypothalamic nuclei— masses of grey matter containing neurons, are located in the white matter in the floor of the third ventricle of the brain. The **neurons** (neurosecretory cells) of hypothalamic nuclei secrete some hormones called **neurohormones** (releasing factors) into the blood. The neurohormones are carried to the anterior lobe of the pituitary gland (= hypophysis) by a pair of **hypophysial portal veins.** In the pituitary gland (hypophysis) the neurohormones stimulate it to release various hormones. Hence the neurohormones are also called "releasing factors".

Hormones as Regulators (Feed Back Control). **Homeostasis** means keeping the internal environment of the body constant. Hormones help in maintaining internal environment of the body. When the secretion of hormones is under the control of factors or other hormones it is called **feed back control**. The regulation of secretion of thyroxine from the thyroid gland is an example of such feed back control mechanism. Feed back control is of two types.

(i) **Positive Feed Back Control.** If the level of thyroxine is less than normal limits in the blood, thyroxine level stimulates the hypothalamus to secrete more of TRH which results in increased secretion of TSH which in turn stimulates increased secretion of thyroxine. Such regulatory effect is called **positive feed back control.**

(ii) **Negative Feed Back Control.** The thyrotropin releasing hormone (TRH) from the hypothalamus stimulates the anterior lobe of the pituitary gland to secrete the **thyroid stimulating hormone** (TSH). The TSH in turn stimulates the thyroid gland to secrete **thyroxine.** A high amount of thyroxine in the blood exerts an inhibitory effect on hypothalamus in such a way that less of TRH and TSH is produced respectively. This eventually results a decrease in thyroxine. This is called **negative feed back control.**

ADDITIONAL INFORMATION

- **Pheromones.** The term pheromone was proposed by **Karlson** and **Butenandt** in 1959. Pheromones are secreted by exocrine glands of the skin and are poured on the surface of the skin hence they were also called **ectohormones.** The smell of these substances affects the mutual behaviour of members of a species. Certain insects secrete pheromones to transmit the information of food sources or danger to their fellow insects. Certain insects secrete pheromones to attract their mating partners.
- **Trophic hormones.** A hormone which stimulates another endocrine gland to secrete its hormone/hormones, is called trophic hormone. For example, thyrotrophic hormone stimulates the thyroid gland to secrete thyroxine.
- In 1923, two Canadian scientists, **Banting** and **Best** succeeded in preparing a pure extract of insulin from the pancreatic islets of a new born calf with the help of Scottish physiologist, **Macleod.** Banting and Macleod won the 1923 Nobel Prize in Medicine or Physiology for the discovery of insulin. Later, **Abel** (1926) succeeded in preparing pure crystals of insulin. **F. Sanger** (1954) worked out the molecular structure of bovine (like an ox) insulin. He received the 1958 Nobel Prize in Chemistry for his discovery. He discovered that insulin is a small protein whose molecule consists of two polypeptide chains, α and β joined by disulphide linkages and respectively formed of 21 and 30 amino acid residues. In 1965, **Tsan** synthesized human insulin.
- **First Insulin Patient.** Banting and Best administered an intramuscular injection of the extract of insulin to 14-year old **Leonard Thompson** on January 11, 1922 in Canada.
- **Glucagon** was discovered by **Kimball** and **Murlin** (1923).
- **E.C. Kendall (1914)** was the first to obtain **thyroxine** in pure form and named it thyroxine. **Harrington** and **Barger** (1927) worked out the molecular structure of this hormone.

They also synthesized thyroxine. The latter's iodine content is about 65%.

- In 1912, **Gudernatch** discovered that metamorphosis in frog's tadpole begins only when adequate amount of thyroxine is secreted by the thyroid of the tadpole.
- **Collip's Hormone**. It was discovered by Collip in 1925. Its crystals were first prepared by **Craig** and **Rasmussen** in 1960. Its molecular structure was worked out by **Potts** and his associates in 1971.
- **Epinephrine** was first extracted by **Abel** (1899) who also named it. It was, however, extracted in pure form by **Jokichi** and **Takamine** (1900). Its molecular structure was worked out by **Aldrich** in 1901. **Stolz** (1904) and **Dakin** (1905) synthesized epinephrine. **Norepinephrine** was discovered by **Ulf von Euler** (1946). Effects of these hormones were studied by **Axelrod** (1965). Euler and Axelrod got Nobel Prize (Medicine or Physiology) in 1970 for their discoveries.
- **Adolf Butenandt** (1929, 1931) discovered the sex hormones. He got the 1939 Nobel Prize (Chemistry) jointly with **Leopold Ruzicka.**
- **Enterocrinin**. This hormone was isolated by **Nasset** from both small and large intestinal mucosa.
- The Father of Endocrinology— **Thomas Addison.**
- **Claude Bernard.** In 1855, he established that the nervous system controls the functions of endocrine glands.
- The term **homeostasis** was given by **Walter D. Cannon** (1920).
- **Contraceptive Pills.** Contraceptive pills contain oestrogen and progesterone.
- **Thyroidectomy**— removal of thyroid gland.
- **Hypophysectomy**— removal of entire pituitary gland.
- **Largest Endocrine Organ.** The gut might be regarded as the largest endocrine organ.
- **Harris** (1955) first suggested that secretion of the hormones of pituitary gland is controlled by certain regulatory factors or hormones secreted by the neurons of hypothalamus.
- **Correct use of iodised salt to prevent Goitre.** 1. Never buy open salt. 2. Iodised salt should be used within six months after purchase. 3. Never transfer iodised salt from its bag to any other container. 4. Always put the iodised salt after full preparation of the dish.
- When under stress, adrenaline is secreted directly into the blood.
- Insulin synthesis is impaired in deficiency of vitamin C.
- Baldness is related to male sex hormones.
- **Guillemin** and **Schally** discovered that brain (hypothalamus) produces peptide hormones. They got the 1977 Nobel Prize in Physiology or Medicine jointly with **Yallow.**
- In 1935, **Ulf von Euler** discovered that human semen contains a very active compound presumably secreted by prostate gland and hence they are named prostaglandins. **Bergstrom, Samuelsson** and **Vane** discovered several types of prostaglandins secreted in vairous tissues and also found the effects of these on physiological processes. They got the 1982 Nobel Prize in Physiology or Medicine for their researches.
- **Chromaffin tissue.** The adrenal medulla belongs to the chromaffin cell system. The cells of this system stain yellow, when treated with some salts of chromium.
- Insulin contains zinc.
- "Four Ss" standing one each for 'salt', 'sugar', 'sex' and 'stress' refer to adrenal glands. It means adrenal glands control salt and sugar metabolism, development of sex and stress reactions.
- A position similar to that of the pituitary gland of the craniates (gnathostomes) is taken by the **Muller's organ** (ciliated oral pit in *Branchiostoma* and the **subneural gland** in tunicates).
- Adrenal glands are also referred to as gland of triple F– Flight, Fight and Fright.
- **21st October**– Iodine Deficiency Disorder Day (IDD Day).
- **14th November**– World Diabetes Day.
- Dopamine, adrenaline and non adrenaline are included under the common name "**Catecholamines**".
- The thyroid gland is homologous to the endostyle of lower chordates.
- **Endorphin** (a peptide hormone) is produced in the brain and anterior lobe of pituitary gland. It inhibits pain perception. Endorphin is called body's natural analgesic or opiate. It is produced at the time of physical or emotional stress.
- The first endocrine disease was named Addison's disease, caused by destruction of adrenal cortex.
- Somatostatin was first isolated from the hypothalamus.

- Oxytocin is responsible for vultures' fate. The vultures are fed on the dead cows and buffaloes injected with synthetic oxytocin, for more yield.
- It was for the synthesis of oxytocin that the American scientist **Vincent du Vigneaud** was awarded Nobel Prize (Chemistry) in 1955.
- Thyroxine (T_4), Tri-iodothyronine (T_3), Adrenaline (epinephrine), noradrenaline (norepinephrine) and dopamine are derivatives of tyrosine (amino acid).
- Women need to check during pregnancy as a temporary phase of diabetes noticed for the first time during pregnancy is known as **gestational diabetes.**
- Happier individuals show lower levels of cortisol, a stress hormone.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Fill in the blanks :

Hormones	**Target Gland**
(a) Hypothalamic hormones	____________
(b) Thyrotrophin (TSH)	____________
(c) Corticotrophin (ACTH)	____________
(d) Gonadotrophins (LH, FSH)	____________
(e) Melanotrophin (MSH)	____________

✓ (a) Pituitary (b) Thyroid (c) Adrenal cortex (d) Gonads (Testes in man and ovaries in females) (e) Skin.

2. Give example(s) of (a) Hyperglycemic hormone and hypoglycemic hormone (b) Hypercalcemic hormone (c) Gonadotrophic hormone (d) Progestational hormone (e) Blood pressure lowering hormone (f) Androgens and estrogens.

✓ (a) Glucagon, Insulin (b) Parathormone (PTH) (c) FSH in both males and females. LH in females ICSH in males (d) Progesterone (e) Atrial natriuretic factor (ANF) (f) Testosterone, Estradiol.

3. Which hormonal deficiency is responsible for the following : (a) Diabetes mellitus (b) Goitre (c) Cretinism.

✓ (a) Insulin (b) Thyroxine (c) Thyroxine

4. Match the following

Column I	**Column II**
(a) T_4	(i) Hypothalamus
(b) PTH	(ii) Thyroid
(c) GnRH	(iii) Pituitary
(d) LH	(iv) Parathyroid

✓ (a)— (ii) (b)— (iv) (c)—(i) (d)— (iii)

5. Define the following : (a) Exocrine gland (b) Endocrine gland (c) Hormone.

✓ (a), (b) and (c) Refer to the text Exocrine glands, Endocrine glands and Properties of Hormones.

6. Diagrammatically indicate the location of various endocrine glands in our body.

✓ Refer to the figure 22.3.

7. List the hormones secreted by the following : (a) Hypothalamus (b) Pituitary (c) Thyroid (d) Parathyroid (e) Adrenal (f) Pancreas (g) Testis (h) Ovary (i) Thymus (j) Atrium (k) Kidney (l) G-I Tract.

✓ Refer to the text Human Endocrine System.

8. Write short notes on the functions of following hormones ; (a) Parathyroid hormone (PTH) (b) Thyroid hormones (c) Thymosin (d) Androgens (e) Estrogens (f) Insulin and Glucagon.

✓ Refer to the text (a) Parathyroid glands (b) Thyroid gland (c) Thymus gland (d) Testes (e) Ovaries (f) Pancreas.

9. Briefly mention the mechanism of action of FSH.

✓ Refer to the text Mechanism of Hormone Action (mode of Hormone Action Through Extracellular Receptors).

TEST QUESTIONS

One Mark Questions (With Answers)

1. Which hormone regulates calcium balance in body ?
   ✓ Parathormone.
2. Which hormone is known as 'birth hormone'.
   ✓ Oxytocin
3. Name the aminoacid from which thyroxine is synthesised.
   ✓ Tyrosine
4. Which endocrine gland is considered "the throne of immunity" ?
   ✓ Thymus
5. Name two hormones that are catecholamines.
   ✓ Adrenaline and nor adrenaline.
6. Where are the hormones of the posterior pituitary synthesised ?
   ✓ In the neurosecretory cells of hypothalamus.
7. Name the disease characterized by a high plasma Na^+, low plasma K^+, rise in blood volume and high blood pressure ?
   ✓ Aldosteronism

Two Mark Questions (With Answers)

1. What is meant by synergistic effect of hormones ? Give an example.
   ✓ **Synergistic effect of Hormones** (i) It is a type of hormonal interaction where two or more hormones complement each others action and both of them are needed for the full-expression of their effects. (ii) Production, secretion and ejection of milk from the mammary glands require the synergistic effect of progesterone, prolactin and oxytocin.
2. Name the hormones secreted by the follicles of thyroid. Give two symptoms of hypothyroidism and name the disease ?
   ✓ The hormones secreted by the follicles of thyroid are thyroxine and calcitonin. Less secretion or hyposecretion of thyroxine from thyroid results in reduced oxidation of food and less tissue metabolism. This disease is known as myxoedema.
3. Why is posterior pituitary known as storage, releaser centre ?
   ✓ Posterior pituitary does not manufacture any hormones but only stores two hormones, vasopressin and oxytocin which are synthesised in the hypothalamus and transported to posterior pituitary. These hormones remain stored in the axon terminals until released into the blood on stimulation. These are then carried in the body via blood as hormones of posterior pituitary. Hence posterior pituitary is known as storage release centre.

Three Mark Questions (Short Answer Type)

1. Which glands are known as glands of emergency ? How adrenal medulla and sympathetic nervous system function as closely integrated system ?
2. A person was complaining of excessive thirst and excretion of large amounts of urine. The treating doctor gave some medicines but did not advise him to stop taking sugar in his food. Name the disease and explain what happens in it ?
3. An adult patient suffers from low heart rate, low metabolic rate and low body temperature. He also lacks alertness, intelligence and initiative. What can be this disease, its cause and cure?

Five Mark Questions (Long Answer Type)

1. What is diabetes? What is the ultimate hormonal deficiency in these diseases? How does this affect an individual's ability to use glucose? What are some possible treatments for diabetes mellitus?
2. Name the hormone that regulates each of the following and mention the source of it. (i) Uterine contraction (ii) Ovulation (iii) Rise in blood sugar (iv) Fall of calcium ion level in blood (v) Urinary elimination of water.

Multiple Choice Questions (With Answers)

(1) Which of the following hormones is a steroid ? (a) Oestrogen (b) Insulin (c) Glucagon (d) Thyroxine.
(Karnataka CET 2011)

(2) Match the source gland with its respective hormone and function and select the correct option.

	Source gland	Hormone	Function
(a)	anterior pituitary	oxytocin	contraction of uterus muscles during child birth
(b)	posterior pituitary	vasopressin	stimulates resorption of water in the distal tubules in the nephron
(c)	corpus luteum	oestrogen	supports pregnancy
(d)	thyroid	thyroxine	regulates blood calcium level *(AIPMT (Pre) 2011)*

(3) Erythropoietin is secreted from (a) pituitary gland (b) pancreas (c) adrenal gland (d) kidney.

(4) The gland which regulates the level of calcium in the blood is (a) Thyroid (b) Adrenal (c) Parathyroids (d) Pituitary. *(HP PMT 2011; Chandigarh CET 2012)*

(5) ACTH is secreted from (a) adrenal cortex (b) pituitary (c) adrenal medulla (d) thyroid. *(UPCPMT 2003; West Bengal JEE 2011)*

(6) The cause of cretinism is (a) hypothyroidism (b) hypoparathyroidism (c) hyperthyroidism (d) hyperparathyroidism. *(West Bengal JEE 2011)*

(7) Which one of the following pairs of hormones are the examples of those that can easily pass through the cell membrane of the target cell and bind to a receptor inside it (mostly in nucleus) ? (a) Insulin, glucagon (b) Thyroxine, insulin (c) Somatostatin, oxytocin (d) Cortisol, testosterone. *(CBSE PMT Prelims 2012)*

(8) What is correct to say about the hormone action in humans ? (a) Glucagon is secreted by β-cells of islets of Langerhans and stimulates glycogenolysis (b) Secretion of thymosins is stimulated with aging (c) In females, FSH first binds with specific receptors on ovarian cell membrane (d) FSH stimulates the secretion of estrogen and progesterone. *(CBSE PMT Prelims 2012)*

(9) In a normal pregnant woman, the amount of total gonadotropin activity was assessed. The result expected was (a) high level of circulating FSH and LH in the uterus to stimulate implantation of the embryo (b) high level of circulating HCG to stimulate endometrial thickening (c) high level of FSH and LH in uterus to stimulate endometrical thickening (d) high level of circulating HCG to stimulate estrogen and progesterone synthesis. *(CBSE PMT Prelims 2012)*

(10) Which of the following is known as master endocrine gland ? (a) Adrenal gland (b) Thyroid gland (c) Pituitary gland (d) Pineal gland. *(Odisha JEE 2012)*

(11) A condition is which the body's internal environment remains relatively constant within limits is (a) Hematoma (b) Homeostasis (c) Haemopoiesis (d) Hemostasis. *(Chandigarh CET 2012)*

(12) Somatostatin is produced in (a) Adenohypophysis (b) Neurohypophysis (c) Pineal gland (d) Basal part of diencephalon. *(HP PMT 2012)*

(13) Which of the following activities is disturbed, if parathyoid gland degenerates? (a) Growth (b) Sodium concentration (c) Potassium concentration (d) Calcium concentration. *(J & K CET 2013)*

(14) Which of the following statements is correct in relation to the endocrine system? (a) Adenohypophysis is under direct neural regulation of the hypothalamus (b) Organs in the body like gastrointestinal tract, heart, kidney and liver do not produce any hormones (c) Non-nutrient chemicals produced by the body in trace amount that act as intercellular messenger are known as hormones (d) Releasing and inhibitory hormones are produced by the pituitary gland. *(NEET 2013)*

(15) Select the answer which correctly matches the endocrine gland with the hormone it secretes and its function/deficiency symptom :

	Endocrine gland	Hormone	Function/deficiency symptoms
(a)	Anterior pituitary	Oxytocin	Stimulates uterus contraction during child birth
(b)	Posterior pituitary	Growth Hormone (GH)	Oversecretion stimulates abnormal growth
(c)	Thyroid gland	Thyroxine	Lack of iodine in diet results in goitre
(d)	Corpus luteum	Testosterone	Stimulates spermatogenesis *(NEET 2013)*

(16) The diurnal rhythms are regulated by .... (a) adrenalin (b) melatonin (c) serotonin (d) vasopressin. *(Maharashtra CET 2014)*

(17) Which one of the following hormones also produces anti-inflammatory reactions in man and suppresses the immune response in addition to its primary functions? (a) Thyrocalcitonin (b) Cortisol (c) Erythropoietin (d) Thymosin. *(Karnataka CET 2014)*

(18) Identify the hormone with its correct matching of source and function. (a) Oxytocin – posterior

pituitary, growth and maintenance of mammary glands (b) Melatonin – pineal gland, regulates the normal rhythm of sleepwake cycle (c) Progesterone – corpus luteum, stimulation of growth and activities of female secondary sex organs (d) Atrial natriuretic factor – ventricular wall, increases the blood pressure. *(AIPMT 2014)*

(19) Which one of the following hormones though synthesised elsewhere, is stored and released by the master gland ? (a) Antidiuretic hormone (b) Luteinising hormone (c) Prolactin (d) Melanocyte stimulating hormone. *(CBSE 2015)*

(20) Which one of the following hormones is not involved in sugar metabolism ? (a) Cortisone (b) Aldosterone (c) Insulin (d) Glucagon. *(CBSE 2015)*

(21) The amino acid Tryptophan is the precursor for the synthesis of (a) Thyroxine and Triiodothyronine (b) Estrogen and Progesterone (c) Cortisol and Cortisone (d) Melatonin and Serotonin. *(NEET-I-2016)*

(22) Graves' disease is caused due to the (a) hyposecretion of thyroid gland (b) hypersecretion of thyroid gland (c) hyposecretion of adrenal gland (d) hypersecretion of adrenal gland. *(NEET-II-2016)*

(23) The posterior pituitary gland is not a 'true' endocrine gland because
(a) it is provided with a duct (b) it only stores and releases hormones (c) it is under the regulation of hypothalamus (d) it secretes enzymes. *(NEET-II-2016)*

(24) Hypersecretion of growth hormone in adults does not cause further increase in height, because
(a) epiphyseal plates close after adolescence (b) bones loose their sensitivity to growth hormone in adults (c) muscle fibres do not grow in size after birth (d) growth hormone becomes inactive in adults. *(NEET 2017)*

(25) GnRH, a hypothalamic hormone, needed in reproduction, acts on (a) anterior pituitary gland and stimulates secretion of LH and FSH (b) posterior pituitary gland and stimulates secretion of oxytocin and FSH (c) posterior pituitary gland and stimulates secretion of LH and relaxin (d) anterior pituitary gland and stimulates secretion of LH and oxytocin. *(NEET 2017)*

(26) A temporary endocrine gland in the human body is (a) corpus cardiacum (b) corpus luteum (c) corpus allatum (d) pineal gland. *(NEET 2017)*

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as–
*(a) If both **A** and **R** are true and **R** is the correct explanation of **A***
*(b) If both **A** and **R** are true and **R** is not the correct explanation of **A***
*(c) If **A** is true but **R** is false. (d) If both **A** and **R** are false.*

1. **(A) :** Eunuchoidism involves aspermia (lack of sperms), underdeveloped sex organs and lack of accessory sex characters in males.
(R) : Failure of progesterone secretion leads to eunuchoidism.
(A) (B) (C) (D)

2. **(A) :** Diabetes insipidus is marked by excessive urination and too much thirst of water.
(R) : Anti-diuretic hormone (ADH) is secreted by the posterior lobe of pituitary gland.
(A) (B) (C) (D) *(AIIMS 2004)*

ANSWERS

Multiple Choice Questions

(1) —a (2) —b (3) —d (4) —c (5) —b (6) —a (7) —d (8) —c (9) —d (10) —c
(11) —b (12) —d (13) —d (14) —c (15) —c (16) —b (17) —b (18) —b (19) —a (20) —b
(21) —b (22) —b (23) —b (24) —a (25) —a

...sertion and Reason Type Questions

(1) —C (2) —B